

**EXPERIMENTAL AND
RESEARCH STATION
CHESHUNT, HERTS.**

ANNUAL REPORT

(THIRTY-THIRD YEAR)

1947

**NURSERY & MARKET GARDEN INDUSTRIES'
DEVELOPMENT SOCIETY, LIMITED**

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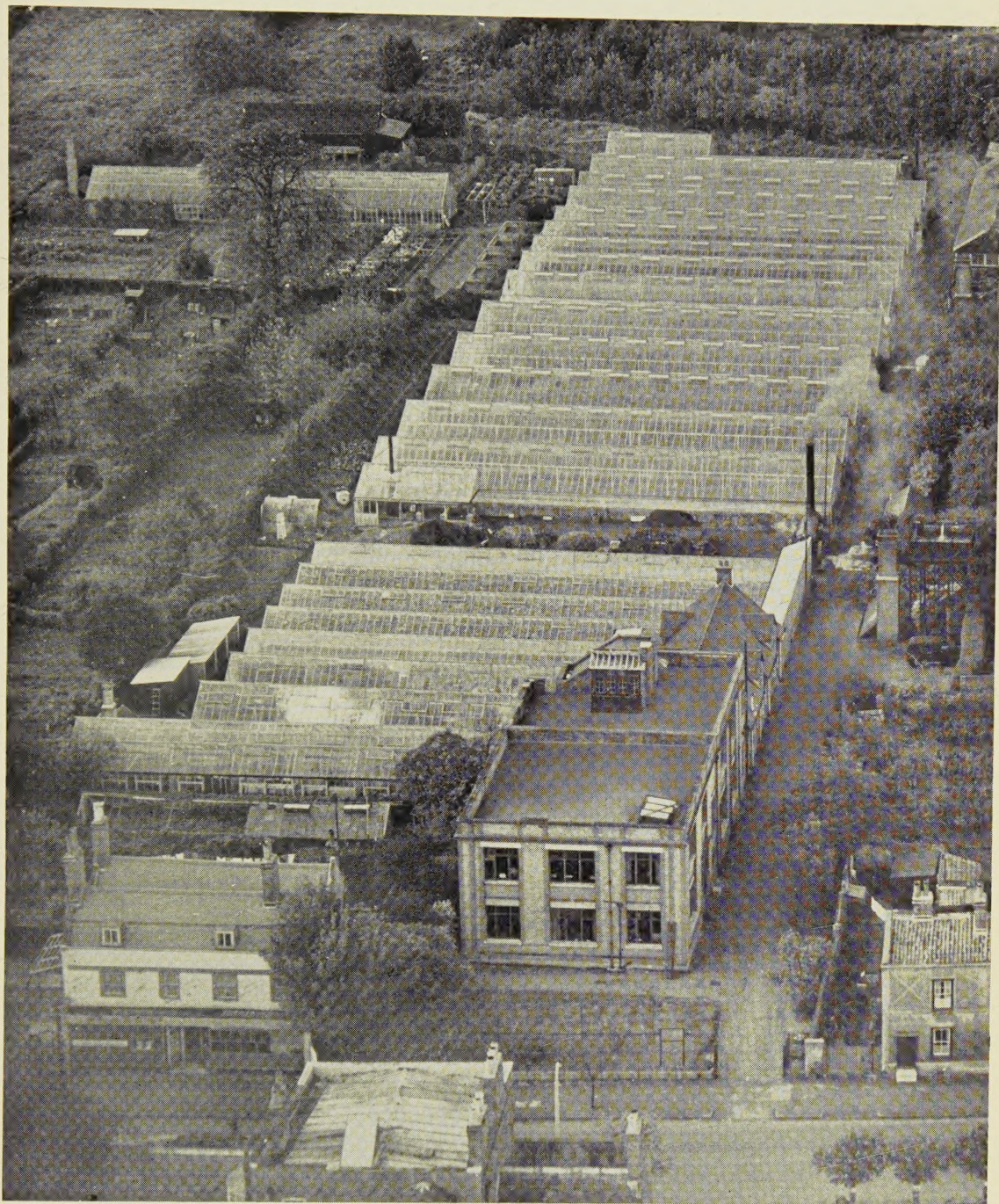
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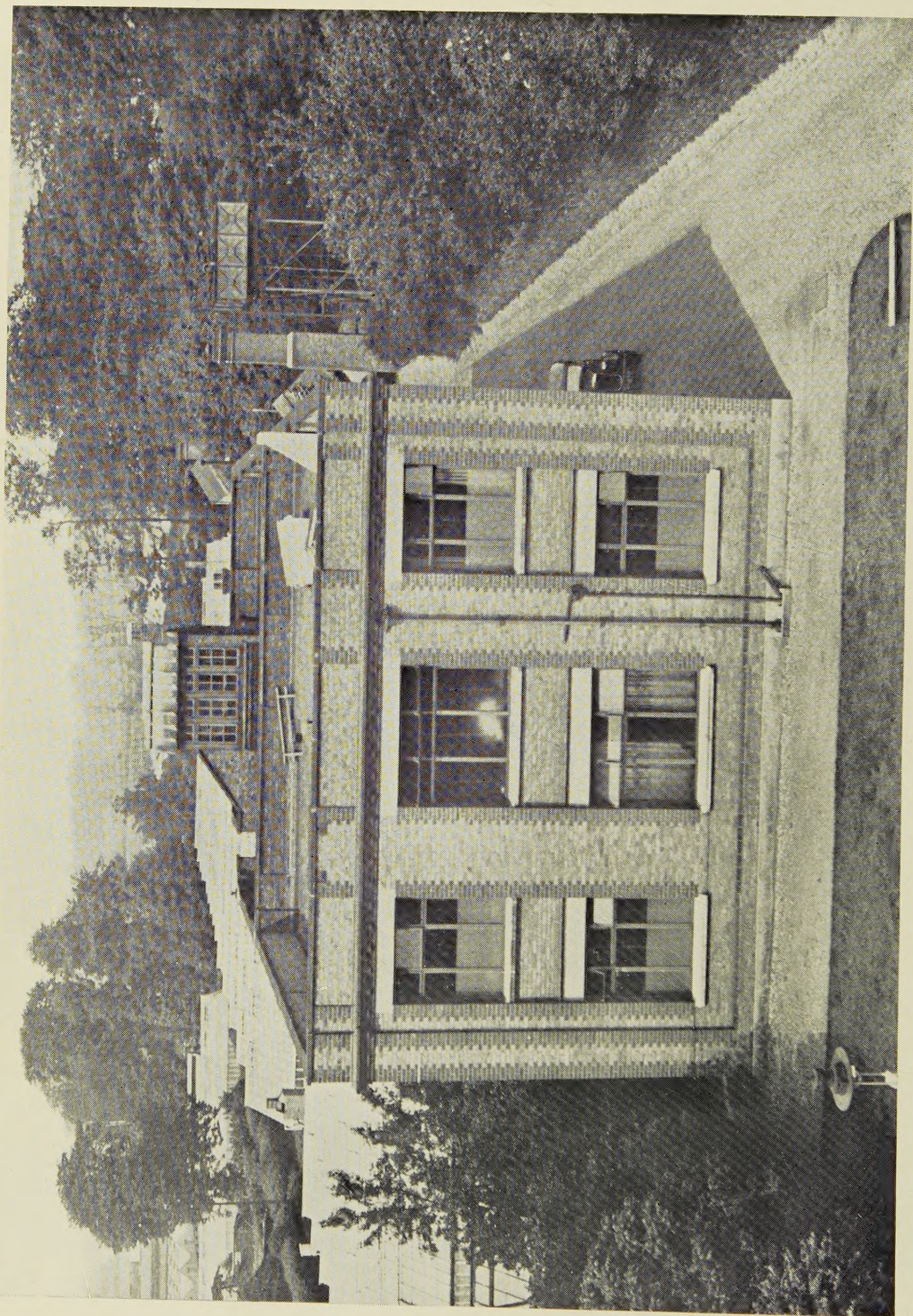
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Diagram showing arrangement of Experimental Plots in 1947.

INTRODUCTION

THE year 1947 will long be remembered for its unusually cold winter, when snow and ice persisted from the end of January until the middle of March, and was followed by disastrous floods in many parts of the country. Many glasshouse properties were among the sufferers and records were made of tomato plants 12-16 ins. high completely submerged in water for three to four days. In some cases the crops were washed out of the ground and had to be replaced by late sowings. Others made a miraculous recovery and many seemed to thrive after the immersion. As might be expected, cases of stem-rot due to *Phytophthora spp.* were reported and it is interesting that in the case of partly-submerged plants infection occurred mainly where they broke the surface of the water. Tomato crops promised well at first but, on the whole, were not more than average.

The work of the Research Station continues its steady progress, but the difficulty of obtaining supplies of all kinds has delayed the investigations.

Current Investigations

An attempt was made to compare the effects of soil sterilization by steam with that of formaldehyde so far as irregular ripening is concerned. The variety Potentate was selected because it is susceptible to this disorder. As was expected, the stronger growth on steamed soil was accompanied by a higher incidence of "blotchy ripening."

Watering experiments are always difficult to arrange, but an attempt was made to provide the plants in different plots with different amounts of water by applying equal quantities at each watering, but at different intervals of time. One series of plots were kept as dry as possible without inducing wilting, while others were watered at intervals of two, four, and seven days respectively. Unfortunately, owing perhaps to the good drainage there was little difference in the plants either in regard to crop yield or quality of the fruit.

An experiment with walls of straw inserted in the soil, one on either side of each double row of tomatoes confirmed previous results and showed an increase of 27 per cent. over the control.

A new experiment has been commenced in houses 11 and 12 to determine the effect of withholding lime and phosphate over a period of years. The first year's results have not revealed any injurious results, but it must be remembered that the soil has been well manured during previous years.

In the variety trials this year a Dutch variety Single Cross, K.C.B., and Radio were superior in quality and crop yield to the other varieties tested.

In the case of cucumbers, straw composted by the Adco process gave yields equal to the best horse-manure when used in the preparation of the beds and in top-dressing.

In preliminary experiments relating to the influence of plant nutrition upon the susceptibility of the tomato to *Didymella lycopersici*, it has been found that excessive nitrogen favoured infection. The disease was much more severe than in plants receiving potash or phosphate and a greater number of plants were infected. Some evidence has been obtained to suggest that an excess of manganese may render the tomato plant more susceptible to infection.

The influence of low temperatures on the spores of *Didymella* has been studied further. Spores in suspension germinated well after being kept at about 23° F. for seven weeks. A spore suspension frozen at 5° F. and allowed to thaw slowly in a refrigerator over a period of 18 hours also germinated well.

The virus investigations have been concerned with the influence of environmental factors on infection. The necessity of maintaining a turgid plant in reducing the severity of virus attack on tomatoes and the beneficial effect of sunlight were demonstrated.

Work on antibiotics has been continued. Tests with various plant materials have shown that sugar beet waste is a satisfactory medium for the production of an antibiotic substance by *Penicillium patulum* which inhibits the growth of several soil organisms pathogenic to the tomato.

During recent years, much information relating to the biology of the Tomato moth (*Diataraxia oleracea* L), both from actual observation and from Continental literature, has been accumulated. An illustrated account of the insect is published in this volume.

Circulars giving all essential information upon the Tomato moth, Greenhouse White-fly (*Trialeurodes vaporariorum* Westw.) and the White-fly parasite (*Encarsia formosa* Gahan) have been published during the current year.

During the past 25 years, a collection of the insects and allied animals associated with the cultivation of glasshouse plants has been made. Many of the specimens in it have been determined by specialists in the various groups concerned. The collection has been scientifically arranged with a view to facilitating the identification of specimens which are, from time to time, brought to the Experimental Station.

At the invitation of the Royal Entomological Society, Mr. Speyer has started to prepare a handbook of British Thysanoptera, which includes the insects commonly known as "Thrips." A translation into English of a considerable portion of Priesner's Monograph of the European Thysanoptera has been completed, but it has become apparent that the descriptions of genera and species and the general classification given by that author for this economically important order of insects require profound modification. The authorities at the British Museum and Dr. C. B. Williams of the Rothamsted Experimental Station have provided facilities for studying the specimens in their respective collections, and an expression of gratitude is proffered to them for their great kindness in so doing.

The control of red spider mites (*Tetranychus telarius* L) by fumigation with azobenzene has been compared in glasshouse trials with that obtained by the use of petroleum emulsion sprays. Azobenzene has given results at least equal to those provided by petroleum emulsions but complete control of the adult mites was not obtained in glasshouse experiments.

The use of thermo-generated azobenzene smokes has been investigated.

Experiments have been commenced with hexaethyltetraphosphate and very promising results have been obtained in preliminary trials. This substance proved considerably more toxic than nicotine to some aphids.

The results obtained in trials at the Research Station and on commercial nurseries with ethyl mercury phosphate for the prevention of losses of tomato plants due to infection by *Didymella lycopersici* at or below soil level failed to yield sufficient information to decide whether the treatment is of value.

Investigations have been carried out regarding the possibility of using sodium alginate as a source of organic carbon in propagating composts. On the criteria of appearance and measurement this material compares favourably with stable manure both for sowing and potting mixtures.

Studies on nitrification have been continued and extended. It has been confirmed that in the case of relatively low applications guano is more rapidly and more completely nitrified than hoof and horn and dried blood. In a soil at an initial pH value of 5.76 addition of superphosphate retarded nitrification in several tests. Addition of lime with the superphosphate reduced this retardation. Addition of potassium phosphate, however, increased nitrate production but this is considered to be due to its alkaline reaction rather than to its phosphate content, as there appears to be no relation between water soluble phosphate and nett nitrate production. The relative order of maximum conversion of nitrogenous material to nitrate when added as a fertiliser and also of some pure organic compounds, is shown to vary at different levels of application at constant temperature. Attention is drawn to the fact that attempts to assess the availability of nitrogen in fertilisers by one or two nitrate determinations after arbitrary periods of incubation may lead to erroneous conclusions and misleading claims. The possibility of using mild hydrolysis with a reagent such as magnesia as a preliminary test of the type of nitrogen present in fertilisers has been explored and has given promising results in relation to the response to different levels of application of the materials. A tentative classification relating the structure of materials to nitrification is suggested.

Work on the various methods of analysis of glasshouse soils has been concluded with attempts to correlate analytical data with plant production and uptake of the main nutrients. Tomato plants were grown in 15 selected soils. The soils were analysed by the methods under review and at the end of the experiment the plants were harvested and analysed for nitrogen, potash and phosphoric acid. In the assessment of the results two criteria have been used. First, the weights of the plants produced and secondly, the actual uptake by such plants of nitrogen, potash and phosphoric acid. On the basis of dry matter production the best correlation is given for potash when the latter is estimated by the N/2 acetic acid method. The same method of extraction gives the highest correlation for potash uptake by the plant. By far the best correlation for the uptake of phosphoric acid

is shown when phosphate in the soil is extracted by distilled water. The most striking results emerge from the data for nitrogen. On the basis of nitrogen uptake by the plant and *total* nitrogen in the soil the correlation is 0.72. There is also a correlation of 0.79 between nitrogen uptake and the cube root of the nitrate-nitrogen concentration in the soils at the commencement of the experiment, and a correlation of 0.82 between dry matter produced and the cube root of the nitrate concentration. Finally, there is a correlation of 0.86 between dry matter production and total nitrogen in the soil. It is suggested that if soil analysis is to have any value for tomato soils it should include a determination of the total nitrogen.

EXPERIMENTAL RESULTS OF 1947

I. TOMATOES

THE practice of grading the tomato fruits from the experimental plots, adopted in 1921, was continued:—

- A. "Pinks" number 5 to 7 and "Pink and White" 8 to 10 to the lb. These are the best quality of fruit in size, shape and colour; "Pinks" being slightly larger than "Pink and Whites."
- B. "Whites." These fruits are of good colour but smaller than "Pink and White."
- C. "Blues." This grade consists of fruits of good colour but larger and more irregular in shape than Grade A.
- D. "Roughs." Small mis-shapen fruits about the size of cherries.
- E. Blotchy fruits which ripen irregularly.
- F. Fruits showing Blossom End Rot.
- G. Fruits showing the lesions of Streak Disease.
- H. Fruits showing "Green Back."

(a) House 1: The Effect of Soil Sterilization upon Blotchy Ripening in the variety Potentate

The house was divided up into four blocks of four plots each, the four treatments in the blocks being as follows:—

- (1) Unsterilized control receiving as a base fertilizer a mixture of equal parts hoof and horn, bone meal, and sulphate of potash at the rate of 12 ozs. per sq. yd.
- (2) Unsterilized control receiving no base fertilizers.
- (3) Steam sterilized: no base fertilizers.
- (4) Treated with formaldehyde: no base fertilizers.

The plants in houses 1-5 were subjected to most unusual treatment and it is surprising they survived. They were planted on March 21st and 12 days later the hot water apparatus broke down. Difficulty in obtaining supplies left the houses unheated for eight weeks during very cold weather. This may have affected the results, but as the plants were still alive when heat was turned on, the crop was left in and continued through the season. The results are given in Table I. The amount of blotchy fruit confirms general experience of Potentate, for the percentage incidence of this disorder is greater in steamed soil than on that treated with formaldehyde. The omission of base fertilisers from this gross feeding variety has increased the percentage of blotchy ripening. This is explained by the fact that the plants in these plots were most severely checked of all the plots by the period of low temperatures.

TABLE I
SOIL STERILIZATION
VARIETY: POTENTATE

Plot	Treatment	Lbs. per Plant	Tons per Acre	Blotchy Fruit %	Average Tons per Acre
2	Control	6.65	50.54	0.1	47.44
5	"	6.16	46.81	8.9	
7	"	5.84	44.38	10.5	
14	"	6.32	48.03	7.9	
3	Control, without C.A.	5.92	44.99	10.9	50.56
8	"	8.17	62.09	7.6	
12	"	6.10	46.36	8.8	
16	"	6.43	48.86	9.7	
4	Steam sterilized: no C.A.	6.85	52.06	13.8	50.64
6	"	6.40	48.64	14.5	
10	"	6.10	46.36	11.8	
15	"	7.38	56.09	9.5	
1	Formaldehyde: no C.A.	6.40	48.64	4.1	52.77
9	"	8.61	65.44	9.4	
11	"	6.26	47.58	12.2	
13	"	6.50	49.40	9.7	

(b) House 4. Manurial Trials

The results shown in Table II include the deficiency plots started in 1916, the soil having been sterilized by steaming in November, 1946. The yield per acre reflects the low level of the essential nutrients in certain plots, and the incidence of blotchy ripening is interesting for it follows the same lines as in the early days of the experiment. Low nitrogen induced blotchy ripening in the fruit to the extent of 3.1 per cent., low potash gave 25.9 per cent., but where phosphate had not been applied since 1916 the amount of blotchy fruit was only 0.1 per cent.

In two plots, namely 4 and 9, a new chrome-leather waste was tested, using it at the rate of 10 cwts. per acre. Base fertilizers and horse-manure were omitted. The yield was average for the house, but it was interesting to note that damage of any kind was absent.

In plots 5 and 7, lime has been omitted for three years without adverse effect and in plots 6 and 8, both lime and phosphates were withheld this year only. The crop was not affected.

TABLE II
VARIETY: AILSA CRAIG

Plot	Treatment	Lbs. per Plant	Tons per Acre	Blotchy Fruit %	Average Tons per Acre
1	C.A.* without Nitrogen	1.90	14.44	3.1	
2	Untreated	1.13	8.58	13.6	
3	C.A.	3.45	26.17	3.8	
10	C.A. plus stable manure	4.08	31.11	0.2	
11	C.A. without phosphate	3.04	23.10	0.1	
12	C.A. without potash	1.29	9.80	25.9	
4	Leather waste before planting: no stable manure	5.21	39.60	2.2	40.89
9	" " " "	5.55	42.18	3.2	
5	C.A. no lime	5.20	39.52	1.5	39.4
7	" " " "	5.19	39.45	0.9	
6	C.A. without phosphates: no lime ...	4.91	37.32	2.0	
8	" " " "	5.30	40.28	0.4	38.80

*C.A. = Complete Artificial.

(c) House 5. Lime and Sulphur Experiments

In this house, plots 2 and 7 received horse-manure, base fertilizers and lime. Plots 3 and 5 were treated similarly except that lime was omitted for the first time this year. The yields were identical and the omission of lime had no effect upon blotchy ripening.

The sulphur experiments were continued in plots 4 and 6, plot 4 receiving 1 lb. and plot 6 $\frac{1}{4}$ lb. flowers of sulphur per sq. yd. There was no obvious effect either upon crop yield or the amount of blotchy fruit. The results are given in Table III.

TABLE III
VARIETY: POTENTATE

Plot	Treatment	Lbs. per Plant	Tons per Acre	Blotchy Fruit %	Average Tons per Acre
2	Horse manure, C.A. and lime ...	4.75	36.70	3.3	36.48
7	" " " " " " ...	4.77	36.25	4.8	
3	Horse manure, C.A.: no lime ...	4.93	37.47	3.0	37.58
5	" " " " " " ...	4.96	37.69	2.8	
4	As 3 and 5, but 1 lb. sulphur per sq. yd. added	4.61	35.04	3.6	
6	As 3 and 5, but $\frac{1}{4}$ lb. sulphur per sq. yd. added	5.14	39.06	2.4	

(d) House 8. Watering Experiment

This watering experiment was arranged so that two plots, 4 and 7, were kept as dry as possible without inducing any wilting of the foliage. Two plots, 1 and 6, were watered once each week,

TABLE IV

House	Plot	Treatment	Crop yield in lbs. per plant							Total tons per Acre	Average tons per Acre	Blotchy Fruit
			May	June	July	Aug.	Sept.	Oct.	Total			
7	1	Planted in the ground ...	—	1.81	1.49	1.79	0.51	0.20	5.80	44.08		0.17
	2	" " cardboard boxes	—	1.92	1.98	2.43	0.49	0.30	7.12	54.11		0.56
	7	" " the ground ...	—	2.04	1.59	1.41	0.58	0.31	5.93	45.07		0.17
	8	" " 9-in. pots	—	2.03	1.69	1.95	0.64	0.19	6.50	49.40		2.01
	3	" " the ground ...	0.17	2.28	1.23	1.63	0.84	0.79	6.94	53.74		0.86
	5	" " " " " "	0.07	2.13	0.94	0.99	0.87	0.57	5.57	42.33		0.18
8	6	" " cardboard boxes	0.14	1.97	1.24	1.41	0.53	0.52	5.81	44.16		0.52
	4	" " 5-in. pots standing on the ground ...	0.22	1.37	1.01	1.00	1.02	0.89	5.51	41.88		1.45
	4	Keep as dry as possible	0.03	2.52	1.13	0.81	0.68	0.36	5.53	42.03	41.27	0.72
	7	" " " " " "	0.03	2.15	1.31	0.95	0.58	0.31	5.33	40.51		0.75
	1	Watered every 7 days	0.08	2.29	1.25	1.17	0.49	0.25	5.53	42.03	42.60	0.90
	6	" " " " " "	0.01	2.35	1.25	0.88	0.63	0.56	5.68	43.17		1.41
9	5	Watered every 4 days	0.01	2.31	1.05	0.54	0.56	0.42	4.89	37.16		1.23
	8	" " " " " "	—	2.17	1.45	1.07	0.64	0.22	5.55	42.18	40.17	0.72
	2	Watered every 2 days	0.05	2.46	1.35	1.14	0.44	0.28	5.72	43.47	43.40	0.70
	3	" " " " " "	0.06	2.45	1.26	0.83	0.61	0.42	5.63	43.33		1.66
	1	Nitrogen as sulphate of ammonia	—	2.27	1.38	1.29	0.70	0.31	5.95	45.22		0.17
	2	" " " " " "	—	2.16	1.14	1.16	0.52	0.23	5.21	39.60	41.54	—
10	3	" " " " " "	—	2.26	1.02	1.15	0.46	0.23	5.12	38.91		—
	4	" " " " " "	—	2.33	1.23	1.29	0.53	0.20	5.58	42.41		—
	5	Control: Standard Treatment ...	—	2.06	1.03	0.72	0.46	0.24	4.51	34.28		—
	6	" " " " " "	—	1.93	1.21	0.84	0.45	0.32	4.75	36.19	39.95	—
	7	" " " " " "	—	1.75	1.08	0.66	0.48	0.32	4.29	32.60		—
	8	" " " " " "	—	2.09	1.35	0.93	0.71	0.28	5.36	40.74		—
10	1	Control: Standard treatment: winter flooded	—	1.32	1.40	1.23	0.83	0.29	5.07	38.53		—
	2	" " " " " "	—	1.36	1.53	1.07	0.81	0.52	5.29	40.20	39.88	0.19
	3	" " " " " "	—	1.41	1.32	1.26	0.92	0.49	5.40	41.04		0.18
	4	" " " " " "	—	1.38	1.36	1.24	0.83	0.42	5.23	39.75		0.20
	5	" " " " " "	—	1.89	1.99	1.56	1.14	0.41	6.99	53.12		—
	6	Straw inserted into the soil as walls: no winter flooding	—	1.93	1.92	1.63	1.03	0.31	6.82	51.83	50.84	—
10	7	" " " " " "	—	1.77	1.81	1.70	0.68	0.34	6.30	47.88		—
	8	" " " " " "	—	1.97	1.84	1.69	0.93	0.22	6.65	50.54		—

VARIETIES.—HOUSE 7: PLOTS 1, 2, 7, 8, AILSA CRAIG; PLOTS 2, 3, 4, 5, POTENTATE. HOUSE 8: POTENTATE. HOUSE 9: E.S.5. HOUSE 10: E.S.6.

which is standard practice except during June, July and August, when if conditions require it two waterings are given each week. Plots 5 and 8 were watered every four days and plots 2 and 3 every two days. The same quantity of water was applied at each watering, namely at the rate of 28,000 gallons per acre. Thus the soil in plots 2 and 3 was always wetter than plots 5 and 8, and these plots were wetter than plots 1 and 6. Plots 4 and 7 were the driest of all. The soil in these houses is over a gravel subsoil and so is very well-drained. This may account for the fact that there was so little difference in the crop yield. If anything, the amount of blotchy ripening was least in the two driest plots. (See Table IV.)

(e) House 9. Nitrogen as Sulphate of Ammonia

In this experiment plots 5-8 received standard treatment, but in plots 1-4 all the nitrogen applied in the fertilizers was in the form of sulphate of ammonia. The results given in Table IV show an appreciable increase in crop yield where sulphate of ammonia was applied. This result is so unexplainable that the experiment will be repeated.

(f) House 10. Straw Walls v. Winter Flooding

Standard treatment was applied to the soil of this house, except that winter flooding was omitted from plots 5-8. Instead walls of straw 2 ins. thick were inserted to a depth of 20 ins., placing the walls one on either side of the double row of tomato plants. Water was applied early by allowing it to run into the subsoil down the straw walls. The plants in the straw-wall plots grew away rapidly from the start and soon overshadowed those in plots 1-4. The increase in yield of 11 tons per acre (see Table IV) is considerable, but the general appearance of the plants gave every promise of this heavier crop from the plots receiving straw. The results confirm those of previous years.

(g) Houses 11 and 12. The Effect of omitting Lime and Phosphate from the Fertilizer Treatment

This experiment, designed to determine the effect of omitting lime and phosphate from the fertilizer treatment applied to the soil before planting the crop will be continued for a number of years.

Plots 1 and 2 in house 11 received standard treatment.

Plots 3 and 4 received the same treatment without lime.

Plots 1 and 2 in house 12 received standard treatment without phosphate.

Plots 3 and 4 received standard treatment without either lime or phosphate.

The records given in Table V do not reveal any harmful effects following the omission of lime and phosphate for one year. The experiment will be continued.

(h) Variety Trials

Variety trials were conducted in house 3 and in the rose house, but the severity of root-knot was so great in the former that any attempt to record crop yields would be useless.

TABLE VI
VARIETY TRIALS

Variety	Tons per Acre	% Blotchy Ripening
Single Cross (Holland) ...	72.12	—
Ogiers K.C.B. ...	67.87	—
Duvaux Radio ...	64.75	—
Woodwards Success ...	64.45	—
Selandia (Norway) ...	63.97	5.75
Bides N.C.O. ...	63.92	—
Stonors All Clear ...	63.51	—
Ragworth Beauty ...	60.95	—
Baby Lea ...	59.89	11.61
Vetomold ...	58.29	—
Tuckswood ...	57.34	0.93
Bruinsma (Holland) ...	55.46	—
L.M.R. No. 1 ...	55.18	—
Tuqueen ...	50.39	—

The most pleasing varieties for weight of crop and quality were Single Cross, KCB and Radio. Selandia and Tuqueen, both Potentate types, are not suitable for the English market; the fruit is large and coarse.

TABLE V

House	Plot	Treatment	Crop Weight in lbs. per Plant					Total Tons per Acre	Average Tons per Acre	% Blotchy
			June	July	Aug.	Sept.	Oct.			
11	1	Complete Artificial	0.34	1.97	2.21	1.19	0.61	6.32	47.95	0.31
	2	"	0.23	1.93	1.93	1.12	0.67	5.88	44.68	—
	3	C.A. less Lime	0.25	1.99	2.00	1.32	0.60	6.16	46.81	0.15
	4	"	0.29	1.90	1.82	1.09	0.54	5.64	42.86	0.16
12	1	C.A. less Phosphate	0.45	2.01	2.84	1.56	0.70	6.56	49.85	—
	2	"	0.40	2.31	2.16	1.57	1.23	7.61	58.28	—
	3	C.A. less Phosphate and Lime	0.44	2.00	2.27	1.52	1.09	7.32	55.63	—
	4	"	0.39	2.35	3.78	1.52	0.83	7.89	59.80	—

VARIETIES.—HOUSES 11: PLOTS 1 AND 4, E.S.1; PLOTS 2 AND 3, AILSA CRAIG. HOUSE 12: AILSA CRAIG.

TABLE VII
VARIETY: BUTCHER'S DISEASE RESISTER.

Plot	Base	Treatment	Crop Yield in lbs. per Plant					Total Tons per Acre	Average Tons per Acre	Total Flats per Foot	Average Flats per Foot
			June	July	Aug.	Sept.	Oct.				
D1	Steamed	Two parts loam, 1 part horse-manure; usual fertilisers	8.34	5.65	7.32	8.01	2.50	38.94	58.41	1.21	1.21
D2	"	"	11.65	7.10	11.21	9.32	3.49	52.57	78.86	1.63	1.63
D6	"	"	6.72	5.87	8.78	5.84	1.53	35.69	53.54	1.11	1.11
E5	"	"	10.54	10.19	8.02	6.31	6.37	48.06	72.09	1.49	1.49
E6	"	"	10.59	8.59	6.17	5.08	3.87	40.97	61.46	1.27	1.27
F3	"	"	13.49	12.11	7.79	6.80	4.10	51.40	77.10	1.59	1.59
D3	"	As above, but fed with nutrient solution	14.07	8.90	13.48	10.45	2.76	59.10	88.65	1.83	1.83
E4	"	"	12.80	11.70	8.85	5.27	4.13	50.58	75.87	1.57	1.57
F5	"	"	10.94	10.41	6.08	6.06	3.29	44.37	66.36	1.38	1.38
D4	"	Two parts loam, 1 part straw composted with A.D.C.O.	10.94	8.19	14.60	10.65	2.88	55.31	83.07	1.72	1.72
F2	"	"	11.83	6.04	6.56	5.52	2.56	41.46	61.19	1.29	1.29
D5	"	As D4 but fed with nutrient solution	11.17	9.75	7.81	4.55	3.62	42.60	63.90	1.32	1.32
E3	"	"	9.78	6.62	11.25	7.76	2.78	46.43	69.65	1.44	1.44
F4	"	"	11.74	8.87	9.81	7.40	4.17	49.75	74.63	1.55	1.55
	"	"	12.06	10.15	8.23	5.06	4.17	47.42	71.13	1.47	1.47

2. CUCUMBER EXPERIMENTS

The cucumber experiments were designed to compare the relative values of composted straw and horse-manure in the preparation of cucumber beds, and also to determine the effect of replacing the standard fertilizers used in the cultivation of this crop by liquid feeding. In eight plots the beds were prepared by mixing two parts of sterilized loam with one part of strawy horse-manure. Three of these were fed with a proprietary soluble fertilizer mixture, the remainder being top-dressed with the standard mixture in the dry state. The diluted solution contained 7 per cent. N, 6 per cent. P_2O_5 and 5 per cent. K_2O . Six other beds were prepared by mixing two parts sterilized loam with one part of straw composted by the Adco process. Of these, three plots were fed in the usual way and three with the soluble fertilizer. The results are given in Table VII.

Crop yields from the horse-manure and straw mixtures were approximately equal, showing as in previous years that composted straw is equal to horse-manure for cucumbers. Neither was there any appreciable difference between the beds fed with the soluble fertilizer and those top-dressed in the ordinary way.

II. PLANT DISEASES

I. DIDYMELLA STEM-ROT

By P. H. WILLIAMS

THE ability of *Didymella lycopersici* to attack the tomato plant is conditioned by a number of factors. Some, such as the manurial treatment, may act mainly through their effect on the plant, making it more or less susceptible to infection. Others like the acidity and moisture content of the soil may act primarily by their influence upon the survival and rate of growth of the fungus in the soil and so may determine the extent of a primary outbreak of this disease. Preliminary experiments on some of these factors are here reported.

The Effect of Major Nutrients

It has been suggested that plants showing a soft type of growth such as that which may accompany cultivation in steamed soil are particularly susceptible to the disease. Such growth is associated in part with excess of nitrogen in the soil and therefore experiments were devised to test the effect of the major plant nutrients on the disease.

Some attempts have been made to administer the nutrients through the leaves by spraying at intervals with solutions of appropriate salts. In a preliminary experiment, small plants in size 60 pots were sprayed with 0.5 per cent. and 0.25 per cent. solutions of potassium sulphate, sodium phosphate and ammonium sulphate, with the addition in each case of 1 in 2,000 sulphonated lorol. The spraying was repeated at weekly intervals for five weeks, the plants being potted on into 32 pots as the increase in size demanded.

Potassium sulphate caused no damage to the plants at either strength nor did ammonium sulphate at 0.25 per cent. At 0.5 per cent., however, ammonium sulphate scorched the edges of the leaves. Sodium phosphate at both strengths caused small yellow spots on the leaves, while the leaflets of the older leaves were bent downwards. Apart from these effects, no differences in growth that could be ascribed to the influence of the nutrients were observed.

It seemed possible that the solutions were not sufficiently strong to produce any noticeable effect on the plants and therefore in a subsequent experiment their strength was increased to 2 per cent., urea being substituted for ammonium sulphate in the hope that it would prove less toxic. Sodium phosphate was omitted owing to lack of space. As before, sulphonated lorol was added to the solutions. The plants, variety Potentate, were potted into size 32 pots before treatment, using a compost containing a little stable manure and lime. Ten plants were sprayed with each solution and there were 10 controls sprayed with water.

Potassium sulphate again proved non-toxic, but marginal scorching of the leaves occurred with urea. In view of this scorching, only one subsequent spraying was given and the strength of the urea solution was halved. The plants, however, were again slightly scorched.

A week after the first spraying, the plants were inoculated by placing a small quantity of scrapings from soaked diseased stems in the surface soil and watering with a spore suspension. The results of the inoculations after five weeks are given in Table I.

TABLE I
EFFECT OF NITROGEN AND POTASSIUM IN SPRAYS ON INFECTION
BY *Didymella lycopersici*

Treatment	Healthy	Diseased	Wilted
Urea	9	1	0
Potassium sulphate	7	3	0
Control	8	2	1

It will be seen that there was no significant difference in the amount of disease between the treated plants and the controls sprayed with water. Also no differences were observed in the appearance of the plants in the different treatments. It would appear that to administer sufficient of the major elements it would be necessary to spray the plants more frequently than has been done

in these experiments. However, in view of the results of an experiment in which the manures were incorporated in the soil, the spraying method was not further investigated.

In this experiment, plants were potted into size 32 pots, using a sterilized compost containing stable manure and 1 per cent. of lime. Sulphate of ammonia, nitrate of potash, sulphate of potash and superphosphate were added to the potting mixture at the rate of 1 per cent. by weight either alone or in combination. The treatments given were as follows:—

- (1) Untreated.
- (2) Sulphate of potash.
- (3) Nitrate of potash.
- (4) Sulphate of ammonia.
- (5) Superphosphate.
- (6) Sulphate of potash, sulphate of ammonia and superphosphate.
- (7) Sulphate of potash and superphosphate.
- (8) Sulphate of ammonia and superphosphate.
- (9) Sulphate of potash and sulphate of ammonia.

There were 10 plants in each series.

A week later the plants were inoculated as before by inserting a small amount of scrapings from diseased stems in the surface of the soil and watering with a spore suspension.

The effect of the dressings of sulphate of ammonia was visible about one week after potting, the plants being a darker green colour than the remainder. The differences were accentuated as growth proceeded. Indeed all the plants receiving nitrogen were dark green with soft growth, while those receiving potash and phosphate were pale green with thinner and harder stems.

The results of the experiment are shown in Table II, the records being taken five weeks after inoculation.

TABLE II
EFFECT OF NITROGEN, POTASSIUM AND PHOSPHATE IN THE SOIL ON INFECTION
BY *Didymella lycopersici*

	Healthy	Diseased	Wilted
K ₂ SO ₄	7	3	0
KNO ₃	1	9	7
(NH ₄) ₂ SO ₄	0	10	8
Superphosphate	8	2	0
K ₂ SO ₄ + (NH ₄) ₂ SO ₄ + superphosphate ...	0	10	10
K ₂ SO ₄ + superphosphate	5	5	0
(NH ₄) ₂ SO ₄ + superphosphate	0	10	10
(NH ₄) ₂ SO ₄ + K ₂ SO ₄	0	10	10
Untreated	7	3	0

The addition of nitrogen not only made the plants more susceptible to infection but increased the severity of the disease as is shown by the number of wilted plants. Further experiments are necessary to determine whether the form in which the nitrogen is applied has any effect on the susceptibility of the plant and the quantity necessary to produce deleterious effects. The addition of potash and phosphate did not affect the susceptibility of the plants to the disease except in the series where they were used in combination. It is doubtful, however, if the difference in this case is significant.

The Effect of some Minor Elements

It is possible that a deficiency or excess of one of the minor elements such as magnesium, boron, etc., may render the tomato more liable to infection by *Didymella*. The latter of these possibilities has been investigated by spraying plants with solutions of certain salts. Tomato plants, variety Potentate, growing in size 32 pots were sprayed with the following solutions, in each case with the addition of sulphonated lorol at the rate of 1 in 2,000:—

- (a) 2 per cent. magnesium sulphate.
- (b) 1 per cent. borax.
- (c) 0.75 per cent. manganese sulphate.
- (d) 0.2 per cent. ferrous sulphate.

Each series contained 10 plants and there were 10 controls sprayed with water only.

The plants sprayed with borax were slightly scorched at the edges of the leaves and, at a second spraying, the strength of the solution was reduced to 0.5 per cent. Later they appeared thin and pale and the lower leaves were badly scorched. None of the other solutions had any ill effects.

A week after the first spraying, the plants were inoculated by placing a small quantity of scrapings from diseased stems in the soil and watering with a spore suspension. Five weeks after inoculation the plants were cut out and the results are shown in Table III.

TABLE III
EFFECT OF SPRAYING WITH SOME MINOR ELEMENTS ON INFECTION
BY *Didymella lycopersici*

Treatment	Healthy	Diseased	Wilted
Boron	7	3	1
Manganese	3	7	0
Magnesium	7	3	0
Iron	6	4	0
Control	8	2	0

With the exception of manganese sulphate none of the treatments caused any marked differences in disease from the control.

Manganese sulphate was again tested in a second experiment. In this case the plants were inoculated when potting into size 32 pots. The pots were filled to within 1 inch of the desired level with the potting compost and then finished off with compost containing about 10 per cent. of a sand-oatmeal culture of *Didymella*. The following day they were sprayed with solutions of manganese sulphate. One series of 10 plants was sprayed with a 0.75 per cent. solution, a second with 0.375 per cent. and there were 10 controls sprayed with water.

The plants sprayed with 0.75 per cent. manganese sulphate became mottled with slight scorching of the lower leaves, some of which died. This scorching was not unexpected in view of the soft type of foliage occurring on plants grown late in the season.

The plants were examined five weeks after inoculation with the results shown in Table IV.

TABLE IV
EFFECT OF SPRAYING WITH MANGANESE SULPHATE ON INFECTION
BY *Didymella lycopersici*

Treatment	Healthy	Diseased	Wilted
MnSOs 0.75% ...	0	10	2
MnSOs 0.375% ...	2	8	3
Control	0	10	6

Almost all the plants were infected, the controls being more severely attacked than the treated plants. This result may probably be attributed to the soft type of growth already mentioned which made all the plants equally susceptible to infection.

The Influence of Low Temperatures on Spore Germination

In the Twenty-ninth Annual Report for 1943, Mrs. Sheard reported that *Didymella* spores were able to withstand up to one hour's exposure to temperatures between 0° C.-10° C. without loss of germinative or infective power. The installation of a refrigerator in the autumn of this year has enabled some additional observations to be made.

(a) A spore suspension in water was prepared to which a little tomato juice was added. Shallow rings cemented to glass slides were filled with this suspension and placed in the freezing compartment of the refrigerator where the temperature was approximately -5° C. Slides were removed at 24-hour intervals and placed in an incubator at 20° C. The last slide was removed after nine days' exposure. In all cases the spores germinated excellently.

(b) Small glass tubes containing 7 ml. of a spore suspension in water were placed in the freezing compartment of the refrigerator. Each day one of the tubes was removed. After thawing, the spores were centrifuged from the suspension, transferred to dilute tomato juice and put to germinate at 20° C.

The germinative capacity of the spores decreased as exposure was prolonged. After six weeks only about 25 per cent. germinated in 24 hours, although the majority still germinated in 48 hours. After a further week the numbers germinating in 24 hours became still further reduced and only about half germinated in 48 hours. When the experiment ended after nine weeks, the power of germination had been almost lost, only about 2 per cent. germinating after 72 hours at 20° C.

(c) A spore suspension was frozen by surrounding the tube containing it with a freezing mixture. A minimum temperature of -15° C. was attained. The vessel containing the freezing mixture and spores was then placed in the refrigerator at about 5° C. and kept there overnight. When taken out after 17 hours, the temperature of the frozen suspension had risen to 0° C. but it had not begun to melt. It was allowed to thaw and drops put on glass slides to germinate at 20° C. There was good germination after 24 hours.

From these experiments it may be concluded that the spores of *Didymella* can withstand much lower temperatures than are normal in this country in the winter. It seems probable that when protected in the pycnidia they would be even more resistant. Up to the present, however, only dried stems have been available and therefore no experiments have been carried out on this point.

2. FUNGICIDES

Didymella Stem-Rot

By W. H. READ

A NUMBER of trials were made with ethyl mercury phosphate as a soil treatment for the prevention of losses of tomato plants due to stem infections by the fungus *Didymella lycopersici* at or about soil level. It is thought that these infections result from the presence of the fungus in the soil and that the severe losses which have occurred on several nurseries after steam sterilization have been due to the re-infection of the soil.

The treatment of the soil before planting by the application of a 1 in 16,000 solution of ethyl mercury phosphate at the rate of 1 gall. per sq. yd. was undertaken on several commercial nurseries, on the majority of which severe losses had resulted for several years due to attack by *Didymella* at the bases of the stems of the plants, in spite of steam sterilization of the soil. Unfortunately very little information of value was obtained from these trials owing to the extremely low incidence of the disease on plants in untreated soil within a period of 12 weeks after planting. Some evidence suggests that the treatment was of value and only on one nursery did the treatment adversely affect the growth of tomatoes.

The reason for the great difference in the losses due to basal infections this year in comparison with those on the same nurseries during previous years cannot be stated. An interesting feature was the prevalence of attacks on the upper parts of the stems late in the season which were not readily attributable to secondary infections arising from primary infections at the bases of the stems.

A further experiment to determine if the application of solutions of ethyl mercury phosphate, dilute tar acid emulsions and a dust containing 5 per cent. salicylanilide were of value in preventing the spread of *Didymella* from diseased to healthy plants also yielded no information. Although 6 per cent of the plants uniformly distributed in a 100-ft. house died as a result of inoculating them with *Didymella* at the bases of their stems all the remaining plants remained free from infection. It is possible that this was due to the abnormally hot weather.

3. VIRUS DISEASES

By R. HOWLES

The Relation between the Susceptibility of Tomato Plants to Virus Infection and certain Physical Factors of the Environment.

Observation of commercial tomato crops infected with virus diseases has long suggested that the severity of the disease is influenced by such factors as atmospheric humidity, water supply, light intensity, temperature and host nutrition.

This year investigations have been started to obtain more accurate information regarding these relationships.

The following method for the preparation of the virus inoculum and the inoculation of tomato plants has been used in all the experiments described in this report.

The virus used was mild tobacco mosaic virus in experiments 1aa, 1ab and 1b, potato virus X in experiments 2b and 3aa, and aucuba-mosaic virus in the remainder.

To prepare the inoculum one gramme of fresh tomato leaf containing virus was ground up with distilled water: the liquid was filtered through cotton wool, and the filtrate made up to 200 ml. with distilled water.

Young plants at the six foliage leaf stage in 3-in. pots (size 60) were used for inoculation.

To inoculate the plants the three terminal leaflets of the fourth foliage leaf from the base of each plant were wiped twice with a pad of cotton wool soaked in the virus solution, and then rinsed with distilled water.

(1) The Relation between Susceptibility to Virus Infection and Atmospheric Humidity

The term atmospheric aqueous saturation deficit, i.e., saturated aqueous vapour pressure less actual aqueous vapour pressure, should be used in preference to relative humidity since the rate at which water is lost by evaporation is proportional to the former quantity.

(a) One day before inoculation 18 plants were placed half in a moist atmosphere (M) and half in a dry atmosphere (D) and maintained there for 10 days.

Two similar glass chambers were used in which conditions of both light and temperature were similar throughout. In chamber M was a large tray containing both water and black cloth on the whole of the bottom. Black cloth soaked with water covered the rest of the floor. The floor of chamber D was covered completely with black cloth. The plants were spaced so that they did not shade one another. The black cloth in each chamber was for preventing reflection of light.

The soil in each of the 18 pots received 100 ml. of water every two days, except during warm weather when this amount of water was given daily, starting shortly before placing the plants in the chambers and continuing until the end of the experiment.

About an hour after inoculation the relative humidity in chamber M was 63 per cent. and the plants were turgid: in chamber D it was 35 per cent. and the plants were wilting.

This experiment was repeated twice (experiments, laa, lab and lac).

The degrees of symptom development in these three experiments are given in Table I.

TABLE I
RELATION BETWEEN SUSCEPTIBILITY TO VIRUS INFECTION AND ATMOSPHERIC HUMIDITY

Experiment	Part of Plant examined for Symptoms	Average degree of Mottling per Plant		Number of Plants which showed Mottling	
		Chamber M Plants	Chamber D Plants	Chamber M Plants	Chamber D Plants
laa	Head	0.43	0.87	1 out of 9	5 out of 9
lab	"			0 " 9	2 " 9
lac	3 inoculated leaflets*	1.33	2.22	9 " 9	9 " 9
lac	Head	0.31	0.75	3 " 9	5 " 9
lba	"	0.0	0.72	0 " 9	6 " 9
lbb	3 inoculated leaflets	1.0	3.06	6 " 9	8 " 9
lbb	Head			1 " 9	4 " 9
lc	"	0.75	0.33	8 " 12	3 " 12

*Examined at the time the plants were taken out of each chamber for the rest of the experiment.

In estimating the susceptibility the following scale was used: No mottling, 0; Very slight mottling, 0.5; Slight mottling, 1; Slight-moderate mottling, 1.5; Moderate mottling, 2; Moderate-much mottling, 2.5; Much mottling, 3; Very much mottling, 3.5.

Discussion

Virus which enters a leaflet as the result of inoculation will diffuse down the phloem to the roots at night and return in the phloem, not xylem, into the shoot system. Factors affecting the rate of development of infection in the head are the amount of virus absorbed at the time of inoculation, the rate of any transpiration current in the phloem, the rate of multiplication of the virus, the virulence of the virus and the susceptibility of the plant to the action of virus. To obtain information concerning these the following experiments were made.

(b) To determine the absorption of virus by the leaf, nine plants were placed in each of chambers M and D for two days. Half-way through this period the 18 plants were inoculated. The chamber M atmosphere was saturated with aqueous vapour using an immersion heater in the tray of water. The relative humidity of the air in chamber D was 49 per cent. This experiment was repeated (experiments lba and lbb). The degrees of symptom development in the two experiments are given in Table I.

These experiments suggest that more virus entered the wilted leaf than the turgid leaf. It is probable that the M plants and D plants were not in chamber M or chamber D sufficiently long to permit any difference in the rate of transpiration, etc., to influence the relative susceptibility. Experiment lc confirms this conclusion.

(c) The effect on the weight of a leaf of immersing it in water was determined. A leaf from a turgid and a wilted plant was detached at the same time. Except for the difference in turgidity, the detached leaves were similar. The upper surface of each leaflet was rubbed with dry cotton wool and then brushed with a small paint brush to remove detached leaf hairs and cotton fibres. On placing, except for the cut end of each petiole, the leaves in distilled water for $1\frac{1}{2}$ hours and afterwards drying them with blotting paper the increases in weight were: turgid leaf 4.6 per cent., wilted leaf 14.75 per cent. This experiment was repeated with similar results.

(d) The rate of transpiration water loss of M plants and of D plants was measured immediately following inoculation. Evaporation from the soil and pot was prevented by covering them with jaconet. Specimen results are in Table II.

TABLE II
TRANSPIRATION DATA

	Chamber M							Chamber D						
	Number of Plant						1-6 mean	Number of Plant						1-6 mean
	1	2	3	4	5	6		1	2	3	4	5	6	
Weight of potted plant and cover 5th May, 1947, 10 a.m. ...	596.5	579	611	597.5	622	604.5		656	704	643.5	657.5	682.5	617	
Decrease in weight during next 23 hours ...	12	22	16.5	30.5	20.5	8	18.2	19.5	19	22	19.5	24.5	14.5	19.8
Decrease in weight from 8 p.m., May 5th, 1947, to 9 a.m., May 6th, 1947 ...	2	1	2.5	2	1	0.5	1.5	0.5	1.5	1	2.5	2.5	1	1.5

Weights: Gm.

May 5th, 1947, 4 p.m.—Relative humidity: Chamber M, 66%; Chamber D, 42%.

According to this experiment the rate of transpiration is not a factor influencing the relative severity of virus symptoms under the conditions of experiment 1.

A possible explanation for this absence of any difference between the rate of transpiration water loss per plant from M plants and from D plants is that rate of loss is limited by rate of entry into the vascular tissue (roots). Wilting causes the stomata to close until rate of loss equals rate of uptake.

(e) To determine the effect of rate of multiplication of the virus, etc., 24 plants were inoculated and next day 12 were placed in each of the chambers M and D for the duration of the experiment. The degrees of symptom development are given in Table I.

The fact that the rate of transpiration is not involved in determining the relative susceptibilities means that from this experiment we conclude that the greater the water content of the plant the greater is the susceptibility caused by the difference in the rate of multiplication of the virus, the virulence of the virus and the susceptibility of the plant to the action of virus.

Discussion of Results of all Experiments in Series 1

Under the conditions of this series, in which transpiration was not a factor influencing the relative rate of virus spread in the plant, the amount of virus absorbed, the rate of virus multiplication, the virulence of the virus and the susceptibility of the plant to virus action control the rate of symptom development. More virus enters a wilted leaf than a turgid leaf but the rate of symptom development for the same amount of virus absorbed is greater in the turgid plant. This means that at first there will be more virus in the wilted plant, later more mottling in the turgid plant.

(2) The Relation between Susceptibility to Virus Infection and Amount of Water added to Soil

(a) The experiment began with eight groups of five plants each, but some were attacked by *Phytophthora parasitica* and so were discarded. The water treatments are given in Table III. As a result of these the plants were at various stages of turgidity between the turgid and wilted states at the time of inoculation.

TABLE III

Group	1	2	3	4	5	6	7	8
Amount in c.c. of water added to soil in each pot each day. According to the prevailing temperature n was $\frac{1}{2}$ or 1 ...	50 n	100 n	150 n	200 n	250 n	300 n	350 n	400 n
No. of plants examined for susceptibility	3	3	3	5	4	4	5	4

Fig. 1 illustrates the results. The head of the plant was inspected. The number of plants in each group when the plants were examined is given in Table III.

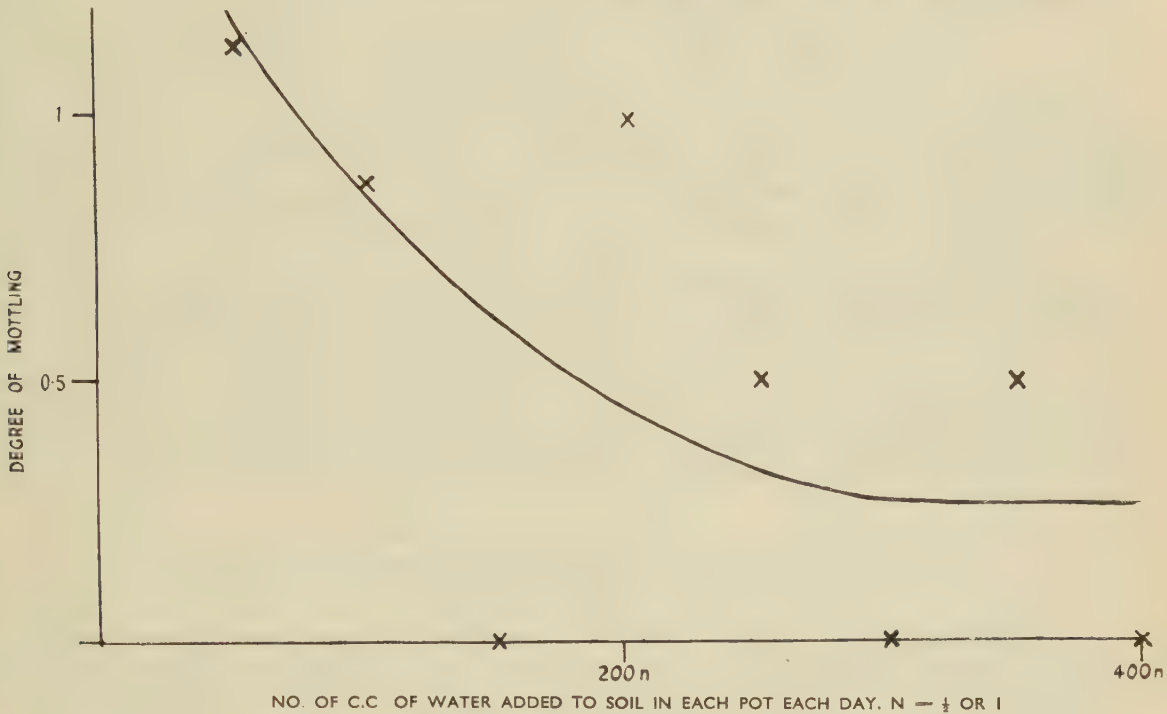


Fig. 1 Relation between susceptibility to virus infection and amount of water added to soil.

Discussion

As in experiment 1 turgidity and possibly rate of transpiration are the two variables in the last experiment. More virus probably entered the wilted leaf but it does not follow from experiment 1e that the more turgid plant was the more susceptible since the chemical difference produced by differential watering is not the same as that due to different humidities. Experiments were performed to obtain (1) the effect of different turgidities at inoculation on the amount of virus absorbed, (2) the effect of differential turgidity produced after inoculation on susceptibility, and (3) transpiration data.

(b) An experiment was carried out in which the relation between the degree of infection with potato virus X and the degree of turgidity at inoculation was obtained. The average number of (1.5 mm. diameter) lesions on the three inoculated leaflets was 1.05 in the case of the turgid plants, 2.75 for the wilted ones. Fifteen turgid and 15 wilted plants were used. That the wilted leaf absorbs more virus than the turgid leaf is confirmed by this experiment.

(c) In this experiment 24 plants were inoculated shortly before half were subjected to one rate of soil watering and the other half to a different rate of soil watering. In the case of W group the soil in each pot received 100 c.c. of water each day. The soil in each pot of the D group only received 100 c.c. of water after inoculation. The results follow. The head of the plant was examined.

				Average degree of Mottling per Plant	Number of Plants which showed Mottling
Chamber W	Plants	...	...	0.97	6 out of 12
"	D	"	...	0.33	3 " 12

The more turgid plant was the more susceptible. Apart from the fact that the rate of transpiration as shown below is a factor in this case, the results confirm those provided by experiment 1e.

(d) The rates of transpiration water loss for two rates of soil waterings were compared. The results are given in Table IV.

TABLE IV
TRANSPIRATION DATA

	Wilting Plants							Turgid Plants						
	Number of Plant						1-6 mean	Number of Plant						1-6 mean
	1	2	3	4	5	6		1	2	3	4	5	6	
Weight in gm. of potted plant and cover ...	608.5	637	687.5	611.5	647	603.5		667	653	688	768	723	692.5	
Decrease in weight in gm. during next 24 hours	11.5	18.5	17.5	14.5	10	15	14.5	74	43	72	84.5	83	85	70

Selman obtained for yellow mosaic virus in the tomato² and for lettuce mosaic virus in the lettuce³ greater susceptibility at higher rates of watering. The plants were inoculated during the differential watering conditions. Bewley and Corbett⁴ had reported that mosaic infection was very severe on nurseries where the water table was high or in houses where waterlogging occurred. These contradictions to experiment 2a are understandable because, if the latter experiment had been continued, the degree of mottling ought to have become greater in the turgid than the wilted plants. Selman² examined his plants for infection a long time (six to eight weeks) after inoculation by which time the relative effect of turgidity probably preponderated over the relative effect due to amount of virus absorbed.

(3) The Relation between Susceptibility to Virus Infection and Light Intensity

(a) Two chambers were erected in which the light intensity in one was half that in the other, the former chamber being coated with green shading. An equal number of plants were used in each chamber. Throughout the experiment the temperature and relative humidity were the same in both chambers. Each plant was inoculated a week after being placed in the chamber.

This experiment was carried out three times—experiments 3aa, 3ab and 3ac. In experiment 3aa 20 *Nicotiana glutinosa* plants (and potato virus X) were used; all leaves were inoculated by rubbing once. In each of experiments 3ab and 3ac 36 (tomato) plants were used.

The degrees of symptom development for the three experiments are given in Table V.

TABLE V
RELATION BETWEEN SUSCEPTIBILITY TO VIRUS INFECTION AND LIGHT INTENSITY

Experiment	Part of Plant examined for Symptoms	Average Degree of Mottling per Plant *		Number of Plants which showed Mottling	
		Unshaded Plants	Shaded Plants	Unshaded Plants	Shaded Plants
3/2aa	All the leaves	8.86*	6.16*		
3/2ab	Terminal 5 leaflets of eighth foliage leaf from base of stem	1.3	1.6		
3/2ac	3 inoculated leaflets	0.18	0.59	3 out of 18	7 out of 18
3/2ac	Head	0.0	0.82	0 " 18	6 " 18
3/2ca	"	0.97	0.57	8 " 15	7 " 15
3/2ca	Later—Head	1.47	1.23	8 " 15	9 " 15
3/2cb	Head	0.57	0.53	9 " 15	11 " 15

*Average number of lesions per plant. The lesions were 2 mm. in diameter.

The results of experiment 3ac confirm the results recently obtained by Bawden and Roberts⁵ in the case of tobacco necrosis, tomato bushy stunt, tomato mosaic and tomato aucuba mosaic viruses. In their experiments a higher virus content was found in the infected plants grown in shade.

Discussion

Turgidity difference of the inoculated leaves may be a reason for the differences in the results. In experiment 3b the effect of immersing the leaves in water was determined. It is also possible that the average thickness of the wall of a leaf hair of a plant unshaded in summer may be greater than in the case of a shaded plant, thus tending to prevent mutilation leading to virus entry (Selman, Bawden and Roberts).

Difference in chemical composition of the unshaded and of the shaded plants is another cause, influencing the rate of multiplication of the virus, the virulence of the latter and the susceptibility of the plant to action by the virus. Bawden and Roberts suggest that some product(s) of photosynthesis inhibit(s) virus multiplication, which is thus able to proceed quicker in shaded plants. Rate of transpiration may be a factor but no transpiration data were obtained. As ultra-violet light is known to destroy virus it is possible that the ultra-violet light of sunlight has some inactivating effect on virus in the plant. Experiment 3c, in which the plants were inoculated before being subjected to differential conditions, was devised to find the importance of light and shade on the development of symptoms. This experiment was done in autumn when the intensity of ultra-violet light was low. It would be interesting to find (by performing in summer an experiment of the form of experiment 2c) if the ultra-violet light of sunlight inactivates virus in the plant.

(b) The effect of placing in water the leaves of unshaded and of shaded plants was ascertained as in experiment 1c. Those from a plant which had been unshaded for one week increased in weight by 1.4 per cent., but in the case of those from a plant which had been shaded for one week the increase in weight was 3.2 per cent. The experiment was repeated with similar results. Both experiments were performed in the afternoon. A morning experiment gave the following results: Unshaded plant 3.1 per cent., shaded plant 3.6 per cent.

It appears that, as in experiment 1 and 2, the turgidity of the inoculated leaf determines how much virus enters it. Here, however, the turgidity is proportional to the rate of photosynthesis, dependent on the light intensity⁶. The greater difference in the case of the afternoon results of experiment 3b may be due to the longer period of light immediately preceding detachment of the leaves. In experiments 3aa, 3ab and 3ac as the period of sunshine and the temperature increase on the day of inoculation so does the difference between the amount of virus absorbed by the unshaded plant and the shaded plant, the former plant absorbing the less. Meteorological data on the day of inoculation were as follows:—

<i>Experiment</i>	<i>Number of Hours of Sunlight</i>	<i>Maximum Temperature, °F.</i>
3aa	0	46
3ab	5.9	65
3ac	11.4	79

In experiment 3aa if an unshaded and shaded plant absorbed almost equal amounts of virus the greater susceptibility of the former plant is possibly caused by its (slightly) greater turgidity, symptoms developing more rapidly with increasing turgidity.

In experiments 3ab and 3ac the average area of a shaded leaf was larger than that of an unshaded leaf, but this should be unimportant since the whole of one side of the leaflet was inoculated. The former leaf was thinner in summer, which is equivalent to increasing the concentration of the virus in the inoculum. The unshaded shoot system of experiment 3aa, carried out in winter, was the slightly larger.

(c) Thirty plants were inoculated and the following day 15 were placed in each chamber and kept there until examined for susceptibility. The experiment was repeated. The degrees of symptom development in the two experiments are given in Table V. ^{3ca} ^{3cb}.

The susceptibility of the unshaded plant being greater than that in the shaded plant—also recorded by Shapovalov and Lesley⁷ for yellows in the tomato—and later the same may be due to the unshaded plant being at first the more turgid of the two plants and afterwards the turgidity difference decreasing. As the plant increases in size the turgidity difference due to difference in rate of photosynthesis may become less because of the greater difficulty of supplying water from the soil to the leaves.

(4) The Relation between Susceptibility to Virus Infection and Temperature

The atmosphere in each of two chambers was almost saturated with water vapour. Any lower relative humidity would mean unequal conditions. If the atmosphere had been saturated there

would have been no transpiration and this may have harmed the plant. An electric fire was placed in one of these chambers.

(a) Twenty-four plants were inoculated and six hours later 12 were put into each chamber for the remainder of the experiment. The fire supplied heat at night only and faced the water in the tray. The maximum temperature in the cooler chamber was 84° F. and in the hotter chamber 98° F.

(b) The fire heated the chamber containing the plants 12 hours immediately before and immediately after inoculating the plants. The maximum temperature in the hotter chamber was 93° F. The other details of the experiment were as for experiment 4a.

(c) The fire supplied heat only during the day and did not face the water in the tray. The maximum temperature in the cooler chamber was 100° F. and in the hotter chamber 115° F. Otherwise the details were as for experiment 4a.

The degrees of symptom development for these three experiments are given in Table VI.

TABLE VI
RELATION BETWEEN SUSCEPTIBILITY TO VIRUS INFECTION AND TEMPERATURE

Experiment	Part of Plant examined for Symptoms	Average Degree of Mottling per Plant		Number of Plants out of 12 which showed Mottling	
		Cooler Chamber Plants	Hotter Chamber Plants	Cooler Chamber Plants	Hotter Chamber Plants
4a	3 inoculated leaflets	0.33	0.62	2	4
4a	Head	0.54	1.08	2	4
4b	"	0.37	0.5	5	9
4c	3 inoculated leaflets	1.33	0.67	8	4
4c	Head	1.87	0.92	8	5

Discussion of Results

Slightly more virus entered the plant at the higher temperature when the latter was below 100° F.

There is a temperature in the region of 100° F. at which the rate of development of virus symptoms in the plant is a maximum. Although tomato aucuba mosaic virus *in vitro* is inactivated by 10 minutes at 80 to 90° C. it is doubtful if complete destruction of the virus in the living plant will occur.

Practical Application of these Experiments

(A) It is unfortunate that, other things being equal, a wilted plant absorbs more virus than a turgid plant but, for the same amount of virus, evidence of virus infection develops more rapidly in the latter than the former. At first there will be more virus in the wilted plant, later more mottling in the turgid plant. Since the turgid plant is the healthier plant the moral is to keep the plant always turgid and so retard the rate of entry of virus into the plant.

(B) The practice of shading glasshouses to reduce the temperature decreases the inhibitory effect of sunlight on development of virus disease. What seems to be required is a shading or glass which although transparent to light yet absorbs the infra-red (heat) radiation of sunshine. A suitable shading is a layer, 3 mm. thick, of 10 per cent. gelatine in water, the liquid solution being mixed with two volumes of 40 per cent. formaldehyde per 100 volumes of the water, coating the layer with clear varnish as soon as it has solidified. Fifty-four per cent. of the radiation from a tungsten filament lamp and incident perpendicularly on the surface of this shading is absorbed by it.

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4. THE CONTROL OF PLANT DISEASES BY MICROBIAL ANTAGONISM

By E. GROSSBARD

The Production of an Antibiotic Substance in Sterilised Soil

In the Annual Reports for 1945 and 1946 an account was given of the production of an antibiotic substance by *Aspergillus clavatus* and *Penicillium patulum* when grown on autoclaved wheat straw to which either water or a glucose solution was added. Continuing these investigations an attempt was made to induce the production of an antibiotic substance in the soil for the purpose of controlling soil-borne plant diseases. Both *A. clavatus* and *P. patulum* are potential antagonists of soil-borne plant parasites. These two fungi produce patulin (clavacin), an antibiotic substance which inhibits the growth of several phytopathogenic fungi and bacteria.

P. patulum was grown on autoclaved soil over-saturated with water. After incubation for 14 days the liquid expressed from the soil was tested against *Bacillus mycoides* and the plant pathogens *Bacterium phytophthorum* and *Phytophthora parasitica*. None of the test organisms were inhibited. As *P. patulum* made good growth in this soil, it appears that this substratum contained the nutrients adequate for the establishment of the fungus but not for the manufacture of the inhibitory substance in any appreciable concentration. Some modification of soil conditions seemed to be necessary. Following up the work on wheat straw which showed that this material is a good medium for antibiotic production in culture flasks, experiments were designed to determine whether incorporation of wheat straw with the soil might induce the formation of an inhibitory substance within the soil.

The Effect of Wheat Straw and Glucose on the Production of an Antibiotic Substance in the Soil

Technique

A soil of the following analysis kindly provided by Dr. O. Owen was used in this experiment.
(Calculated for soil dried at 100° C.)

Total nitrogen	...	...	...	...	...	0.41 per cent.
Organic carbon (Walkley and Black)	...	...	...	...	...	3.23 "
Potash (soluble in 1 per cent. citric acid) K ₂ O	...	...	...	...	...	0.029 "
Phosphoric acid (soluble in 1 per cent. citric acid) P ₂ O ₅	...	...	...	...	...	0.015 "
Carbonates	...	...	...	...	...	Slight traces
p.H.	...	...	...	...	...	5.52

After passage through a 2 mm. sieve and drying at 105° C., 200 g. were placed in 500 ml. flasks and the following treatments were carried out:—

- (1) 200 g. of soil were mixed with 40 per cent. (of the total weight) of distilled water.
- (2) 200 g. of soil were mixed with (a) 2.5 per cent., (b) 3.5 per cent., and (c) 5 per cent. of wheat straw from the 1946 harvest (chaffed and ground by an electric mill) and 50 per cent. of water to allow for the absorption by the straw was added.
- (3) As in (1), but 2.5 per cent. of glucose was added.
- (4) 200 g. of soil were mixed with 5 per cent. of straw, 50 per cent. water and 2.5 per cent. of glucose was added.

The flasks were autoclaved for one hour at 15 lbs., inoculated with 1 ml. of a spore suspension of *P. patulum* (P.189) and incubated for 14 days at 25° C. Controls were set up in an identical manner but omitting inoculation with the fungus. After incubation each sample was placed in a coarse cloth and compressed by hand. The expressed liquid was filtered, steamed for 15 minutes and then assayed against *B. mycoides*, *Corynebacterium fascians*, *B. carotovorum* and *B. phytophthorum*.

The liquid expressed from soils containing either 2.5 or 3.5 per cent. of straw or 2.5 per cent. of glucose were tested against *Phytophthora cryptogea* and *P. parasitica*.

For the antibacterial and antifungal tests the serial dilution method was used. The results are given in Tables I and II.

TABLE I
THE ANTIBACTERIAL ACTIVITY OF THE LIQUID EXPRESSED FROM SOILS CONTAINING WHEAT STRAW OR GLUCOSE OR BOTH
AND INOCULATED WITH *P. putulum*.

Substratum	pH*	Test Organisms									
		<i>B. mycoides</i>				<i>B. carotovorum</i>		<i>B. phytophthorum</i>		<i>C. fascians</i>	
		Initial	After Incubation	Inhibition	Concentration Required	Inhibition	Concentration Required	Inhibition	Concentration Required	Inhibition	Concentration Required
Soil	5.25	5.89	None	—	None	—	None	—	None	—	
Soil plus 2.5% Straw	5.03	4.86	Partial	1 : 5	Complete	1 : 5	Partial	1 : 5	None	1 : 5	
" " 3.5% "	4.93	5.18	Complete	1 : 5	Complete	1 : 10	Complete	1 : 5	None	—	
" " 5.0% "	5.02	5.25	Complete	1 : 10	Complete	1 : 20	Complete	1 : 10	Complete	1 : 10	
" " 2.5% Glucose	5.63	4.93	Complete	1 : 40	Complete	1 : 40	Complete	1 : 40	Complete	1 : 20	
" " 5% Straw,											
plus 2.5% Glucose	4.99	4.60	Complete	1 : 80	Complete	1 : 80	Complete	1 : 80	Complete	1 : 40	

*We are greatly indebted to Dr. O. Owen for the pH determinations.

TABLE II
THE ANTIFUNGAL ACTIVITY OF THE LIQUID EXPRESSED FROM SOILS CONTAINING WHEAT STRAW OR GLUCOSE
AND INOCULATED WITH *P. putulum*

Substratum	Test Organisms			
	<i>Phytophthora cryptogea</i>		<i>Phytophthora parasitica</i>	
	Inhibition	Concentration Required	Inhibition	Concentration Required
Soil	None	—	None	—
Soil plus 2.5% Straw	Growth stimulated.	1:10	Growth stimulated.	1:5
" " 3.5% "	Complete	1:20	Complete	1:10
" " 2.5% Glucose	"	1:100	"	1:100

pH as in Table I.

The data in Table I suggest that *P. patulum* produced an antibiotic substance in sterilized soil in the presence of wheat straw. Its inhibitory power was greatly increased when glucose was added. When the straw was replaced by glucose the degree of inhibition was considerably greater, in comparison with a soil containing the equivalent weight of straw. It is suggested, therefore, that it is the decomposition of carbohydrates which induced the formation of an antibiotic substance in sterilized soil by *P. patulum*. Table I shows that the liquid expressed from an inoculated soil lacking either straw or glucose did not inhibit the growth of the test organisms. This fact is not a conclusive proof that an antibiotic substance has not been formed at some stage. At low concentrations adsorption may have taken place. Other methods of extraction, which have yet to be examined, may demonstrate the presence of an adsorbed inhibitor.

Experiments are in progress to show the degree of inhibition exerted by this antibiotic substance produced in the soil on the growth rate of phytopathogenic fungi and the number of viable cells of phytopathogenic bacteria living in the same soil. It is hoped that in this experiment the action of any adsorbed substance will become apparent. Results are not yet available.

The Antibiotic Activity of Cultures of *P. patulum* growing on several Organic Materials

To obtain a good concentration of the antibiotic substance produced by *P. patulum* in sterilized soil a supply of glucose in addition to incorporation with wheat straw is necessary. This is not a practical proposition and therefore several other plant materials were examined in an effort to find one superior in effect to wheat straw. The following plant materials were tested and compared with wheat straw:—

- (1) Fresh wheat straw of the 1946 harvest: finely chaffed.
 - (2) Wheat straw composted with Adco and left to decompose for 15 months.
 - (3) Sugar beet pulp. The finely divided and dried pulp of the sugar beet after the extraction of the juice, mixed with molasses was used.
 - (4) Irish sphagnum peat.
 - (5) Bracken; cut after maturity late in September.
 - (6) Yellow mustard; the crop was cut just at flowering time. The entire plant—leaves, stems, flowers and roots—was used.
 - (7) Sainfoin.
 - (8) Lucerne.
- Both sainfoin and lucerne were cut and tested as the yellow mustard.
- (9) Fescue; cut in August. Owing to the dry season the grass was very dry, almost hay. It was used as a cover crop in an orchard.

Sainfoin, yellow mustard, lucerne and fescue were air-dried in the laboratory and then cut into short lengths. The plants were tested in the following way.

Technique

To 10 g. of the plant material were added 100 ml. of water or 100 ml. of a glucose solution, bringing the final concentration of glucose to 3.5 per cent. of the total weight.

The materials were sterilized and inoculated with *P. patulum* (P 189). No glucose was added to the sugar beet pulp, but instead of 100 ml. of water, 120 ml. were added to this and also to the peat because of the considerable absorption power of these two materials. After one week's incubation samples of the culture fluid were drawn off and their inhibitory power was tested against *B. mycoides* using the cylinder plate method described in the Annual Report for 1946. There was, however, one small modification in the technique. While in previous experiments Difco agar was bulk seeded with an undiluted suspension of the test organism, in these tests the bacterial cultures were diluted 10 times, giving a final concentration of 1 : 200. Zones tended to be larger but the outlines were much better defined and thus the process of recording was simplified. A greater dilution, as recommended by other workers, was found to be less satisfactory under the conditions of this experiment. The results are tabulated below in Table III.

The above figures show that molassed sugar beet pulp is a very satisfactory medium for the production of an antibiotic substance by *P. patulum*. The culture fluid was even more active than that from any other plant material to which a glucose solution had been added. Among other materials tested bracken was almost as effective as fresh wheat straw. The inhibitory agent was found to persist on both materials for a considerable period of time, although the vegetative growth and spore formation was somewhat slow and sparse. On all other materials, including the sugar beet pulp the fungus grew rapidly, covering the substratum profusely with a great mass of spores

TABLE III
THE ANTIBACTERIAL ACTIVITY OF THE CULTURE FLUID OF *P. patulum* GROWING ON
SEVERAL ORGANIC MATERIALS.
Test Organism: *B. mycoides*, cylinder plate method.

Substratum	Growth and Spore Formation	Inhibition	Diameter* of Area of Inhibition
Fresh Wheat Straw:			
(a) Plus Water	Slow and sparse.	Complete.	20.0
(b) „ 3.5% Glucose	Slow but good.	„	27.0
Composted Wheat Straw:			
(a) Plus Water	Rapid and very profuse.	None.	0.0
(b) „ 3.5% Glucose	„ „ „	Complete.	25.0
Sugar Beet Pulp	„ „ „	„	29.0
Irish Spagnum Peat:			
(a) Plus Water	None or very poor.	None.	0.0
(b) „ 3.5% Glucose	Rapid and profuse.	Complete.	25.0
Bracken:			
(a) Plus Water	Slow and sparse.	Complete.	17.0
(b) „ 3.5% Glucose	Slow but good.	„	27.0
Mustard:			
(a) Plus Water	Rapid and profuse.	None.	0.0
(b) „ 3.5% Glucose	Very rapid and very profuse.	Complete.	27.0
Sainfoin:			
(a) Plus Water	Rapid and profuse.	None.	0.0
(b) „ 3.5% Glucose	Very rapid and very profuse.	Complete.	20.0
Lucerne:			
(a) Plus Water	Rapid and profuse.	Partial.	10.0
(b) „ 3.5% Glucose	Very rapid and very profuse.	Complete.	28.0
Fescue:			
(a) Plus Water	Rapid and profuse.	Complete.	17.0
(b) „ 3.5% Glucose	„ „	„	26.0

External Diameter of Cup: 0.8 millimetres.

* Mean to the nearest millimetre.

three days after inoculation. On lucerne and fescue an inhibitory substance was formed at a very early stage, but it tended to disappear rather rapidly, especially in the lucerne cultures. The addition of glucose to any of these materials resulted in the production of an antibiotic substance of greater activity and stability. The length of time during which activity was maintained was, however, shorter in all cases as compared with the cultures on wheat straw and glucose. Yellow mustard and sainfoin gave poor results. Peat without the addition of glucose did not even support the growth of the fungus, but when glucose was added the inhibitor was very active and persisted for many months. The above results may not be regarded as final. It is quite probable they will vary with the stage of development of the plant at which it was harvested.

Materials found to be satisfactory will be tested at different times of the year, taking samples from different localities.

Tests are in progress with other materials including rye grass, clover, seaweed and sodium alginate.

The Effect of Sugar Beet Pulp on the Production of an Antibiotic Substance in the Soil

The results in Table III showed that molassed sugar beet pulp was a very satisfactory medium for the manufacture of an antibiotic substance by *P. patulum*. Experiments were therefore carried out incorporating sugar beet pulp with sterilized soil and inoculating this medium with *P. patulum*. The soils were subsequently treated as described in the paragraph on the incorporation of wheat straw. Two levels of sugar beet pulp, namely 2.5 per cent. and 5 per cent., were used. Test organisms were *B. mycoides*, *B. carotovorum*, *B. phytophthorum* and *Corynebacterium fascians*. The liquid expressed from a soil containing 2.5 per cent. sugar beet pulp was tested against *Phytophthora parasitica*. The results are set out in Table IV. Figures I and II show a comparison of results obtained from soils containing an equivalent amount of either wheat straw or glucose or sugar beet waste, using *B. carotovorum* and *Phytophthora parasitica* as test organisms.

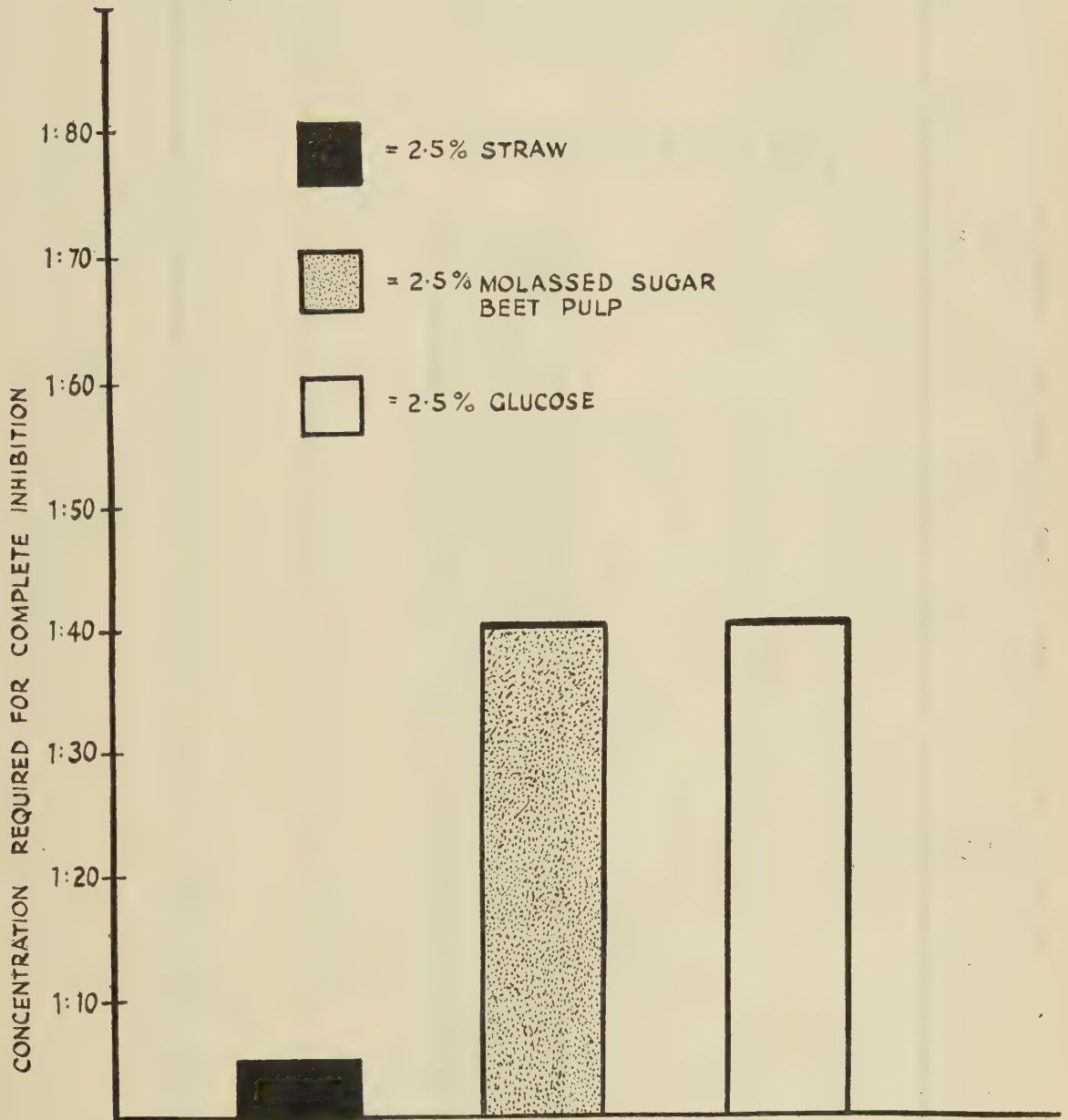


FIG. 1

The inhibitory effect on *B. carotovorum* of the liquid expressed from soils containing equivalent quantities of three different carbohydrates.

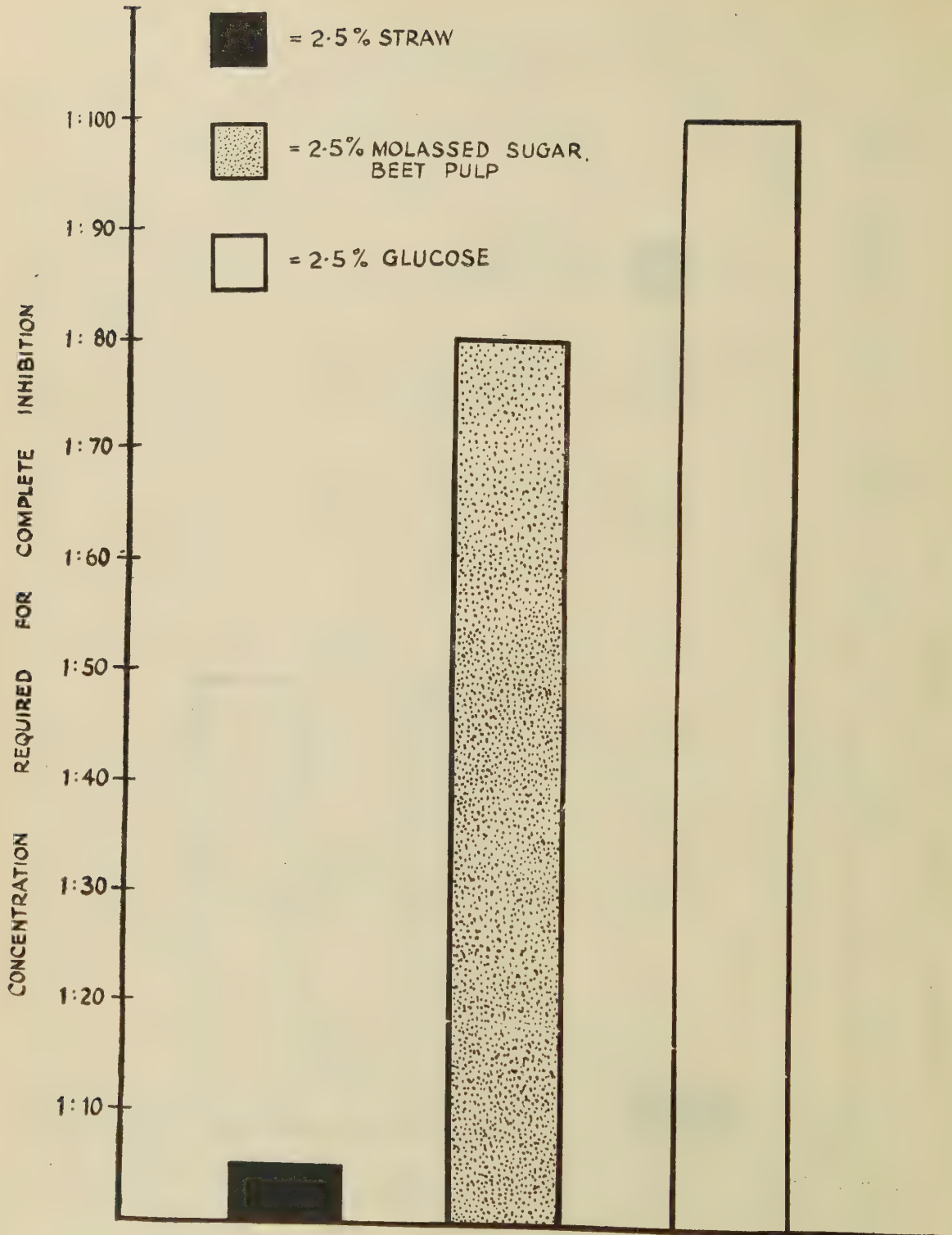


FIG. 2

The inhibitory effect on *Phytophthora parasitica* of the liquid expressed from soils containing equivalent quantities of three different carbohydrates.

TABLE IV
THE ANTIBACTERIAL ACTIVITY OF THE LIQUID EXPRESSED FROM SOILS CONTAINING SUGAR BEET PULP.

Substratum	Test Organisms									
	pH		<i>B. mycoides</i>			<i>B. carotovorum</i>			<i>B. phytophthorum</i>	
	Initial	After Incubation	Inhibition	Concentration Required	Inhibition	Inhibition	Concentration Required	Inhibition	Concentration Required	<i>C. fascians</i>
Soil plus 2.5% Sugar Beet Pulp ...	4.77	4.94	Complete	1 : 40	Complete	Complete	1 : 40	Complete	1 : 40	1 : 20
Soil plus 5% Sugar Beet Pulp ...	4.96	4.84	Complete	1 : 40	Complete	Complete	1 : 40	Complete	1 : 40	1 : 40

TABLE V
THE ANTIBACTERIAL ACTIVITY OF WHEAT STRAW, CULTURE-FLUIDS OF THREE ANTAGONISTIC ORGANISMS

Antagonist	Test Organism			
	<i>B. mycoides</i>		<i>B. phytophthorum</i>	
	Inhibition	Diameter of Area	Inhibition	Diameter of Area
<i>A. terreus</i> ...	Complete.	20	None.	0
<i>P. patulum</i> ...	Complete.	20	Complete.	27
<i>S. antibioticus</i> ...	Complete.	15	None.	0

TABLE VI
MEAN PERCENTAGE OF SEEDLINGS EMERGED AND MEAN PERCENTAGE OF EMERGED SEEDLINGS WHICH SUBSEQUENTLY BECAME DISEASED, EIGHT WEEKS AFTER EMERGENCE.

Substratum	Infected with <i>P. patulum</i>				Not infected with <i>P. patulum</i>			
	General Inoculation		Localised Inoculation		General Inoculation		Localised Inoculation	
	Emerg.	Diseased	Emerg.	Diseased	Emerg.	Diseased	Emerg.	Diseased
1 Soil ...	81	83	70	49	73	93	78	55
2 Soil plus Glucose ...	80	82	76	44	67	87	78	53
3 " " Straw ...	82	94	82	71	80	96	90	52
4 " " " plus Glucose	81	84	75	32	74	79	89	48

Rate of emergency in soils not inoculated with *Phytophthora parasitica* was 96%.

The results in Table IV and in Figures I and II show that dried molassed sugar beet pulp is a much more satisfactory means to induce antibiotic production in sterilized soil by *P. patulum* than is wheat straw. It can well replace applications of glucose. Although costs are high at the present moment sugar beet pulp is certainly cheaper and more practicable than the watering of soils with a glucose solution. The influence of this material of a considerable water-holding capacity and high carbohydrate content (58.3 per cent.) on the general conditions of the soil calls for detailed investigation.

Discussion

The above experiments with straw, glucose and sugar beet pulp showed that carbohydrate decomposition induced the antibiotic activity of one specific organism, namely *P. patulum*, at least in sterilized soil. As the sterilization of soils is a routine process in the glasshouse industry the requirement of sterilized soil is not an obstacle. It should be noted that this work has been carried out with autoclaved soil, that is, soil which was completely sterile. On partially sterilized soil results may be different. These experiments are being repeated on a soil which has been sterilized by steam, according to the usual commercial practice.

West and Hildebrand,¹ Sanford,² Garrett,³ Grossbard working with different root diseases reported a decrease in the virulence of attack when glucose was added to the soil and attributed this suppressing effect to a beneficial modification of the microflora of the infected soils brought about by the increased carbohydrate decomposition. It is tentatively suggested that the effect of glucose or any source of carbohydrate is not limited to a qualitative and quantitative alteration of the microflora but that in addition the production of antibiotic substances may be encouraged in the soil, not only by *P. patulum*, but also by other micro-organisms.

The controlling effect of glucose on root diseases is not a general one. Many workers report that certain root diseases are stimulated rather than reduced by the addition of glucose. In the report for 1946 an account was given of two experiments on damping-off where control was attempted by the inoculation of soils with *Aspergillus clavatus* and the incorporation of straw or glucose or both. In one experiment glucose effected a marked decrease in the number of damped-off seedlings in both controls and treatments. In the second experiment carried out under different conditions damping-off was much more severe in boxes inoculated with *A. clavatus* and treated with glucose. The action of carbohydrate decomposition on microbial antagonism and consequently on disease control is not clear at present and a great deal of work has yet to be done before the incorporation of manures rich in carbohydrates can be recommended.

Experiments on the Persistence of the Inhibitory Agent in Wheat Straw Cultures of *P. patulum*

An experiment was carried out to determine how long the antibiotic activity is maintained in wheat straw cultures of *P. patulum*. Fresh straw, as well as straw composted by the Adco method, was used. The cultures were sown in August and tested at intervals. The extracts from the fresh wheat straw and water medium were still active after four months but began to lose activity after five months. Merely weak traces could be detected after six months, while the fresh straw-glucose culture extracts were still active seven months after sowing. The composted straw culture in the absence of glucose did not inhibit the test organism completely at any stage of these investigations. The addition of glucose produced a highly active and persistent antibiotic substance which retained its potency for four months. For the purpose of these tests the free culture fluid had been removed entirely after two months and from then onwards the straw was leached at intervals with sterile distilled water. These leachates still contained the inhibitory substance. It may be assumed that on the fresh straw cultures the fungus continued to produce the antibiotic substance for some time but on the composted straw cultures manufacture must have ceased as soon as all available glucose was used up. That the leachates still contained the inhibitory agent even after four months can only be explained by the fact that the straw must have retained a proportion of it and that this portion was extracted, and eventually removed entirely by leaching. This property of retention of the inhibitory agent by the straw and the slow process of leaching out by water may be of significance in any future practical application of this work in the field. Even if fresh straw were incorporated with the soil for the purpose of antibiotic production sooner or later it will become decomposed and antibiotic manufacture may cease. It will then be important that the decomposed straw should conserve the inhibitory substance in the soil for some length of time.

The Persistence of the Antibiotic Substance under Septic Conditions

Samples were drawn off the straw cultures of the above experiment two weeks after inoculation. They were diluted with water and left to stand under conditions which allowed contamination. These samples were tested at intervals for antibiotic activity and it was found that they retained their activity for four months after which time potency gradually decreased. On the whole the substance can be regarded as being very stable.

Other Antagonistic Organisms which produce an Antibiotic on Wheat Straw

Other organisms besides *P. patulum* which are known to produce antibiotic substances were cultured on autoclaved wheat straw to which water was added, and tested against *B. mycoides* and *B. phytophthorum*.

The antagonists examined were: *Aspergillus fumigatus*, *A. terreus*, N.C.T.C. No. 3911 *Bacillus subtilis*, *Penicillium gladioli*, N.C.T.C. No. 3994, *Streptomyces griseus* and *S. antibioticus*.

The first preliminary test showed that among these organisms *A. terreus* and *S. antibioticus* gave positive results and further work was concentrated on these two antagonists. The results of a test with *A. terreus* and *S. antibioticus* are given below in Table V. For the sake of comparison, tests with *P. patulum* were included.

The results in Table V show that *A. terreus* and *S. antibioticus* are capable of producing on wheat straw a substance which inhibits the gram-positive *B. mycoides* but not the gram-negative *B. phytophthorum*, while the cultures of *P. patulum* are active also against gram-negative bacteria. Tests for antifungal activity are in progress. Brian and Hemming¹ reported that *A. terreus* is antagonistic to *Botrytis allii* and experiments here with *S. antibioticus* showed that the latter inhibits the growth of *Colletotrichum atramentarium* when both organisms were grown together on a plate containing Difco agar. Experiments have been set up incorporating wheat straw with sterilized soil and inoculating the soils with *A. terreus* or *S. antibioticus*. Extracts from these soils will be tested for inhibitory action against *Botrytis allii* and *C. atramentarium* respectively.

The Introduction into Sterilised Soil of *P. patulum* and its possible effect on the Control of Damping-off of Tomato Seedlings

In the last two reports for 1945 and 1946 experiments were described which were designed to control damping-off of tomato seedlings by the antagonistic action of *A. clavatus* on the responsible parasite *Phytophthora cryptogea*. A similar experiment was carried out in 1947. As antagonist *P. patulum* was chosen and the causative agent for damping-off was *Phytophthora parasitica*. The technique of this experiment was similar to that described in the trial on the effect of *A. clavatus* on damping-off in the report for 1946. It consisted in the inoculation of 3,000 g. of sterilized soil in seed boxes with either 200 g. of a sand oatmeal culture or 60 g. of a wheat straw culture of *P. patulum* and the subsequent spraying of these boxes at regular intervals with either 300 ml. of water or 300 ml. of a 4 per cent. glucose solution. After 14 days incubation in a glasshouse *Phytophthora parasitica* was introduced. This inoculation was either a general one, that is, 200 g. of the *Phytophthora* culture were mixed evenly with the compost of each box, or a localised one. In the latter case the compost was divided into three parts, about two-thirds of the centre portion were removed and the remaining one-third was mixed with 200 g. of the parasite culture and placed into the centre of the box. Every effort was made to ensure a uniform inoculum of both *P. patulum* and *Phytophthora parasitica*. After a further period of incubation of three weeks, 150 tomato seeds were sown per box as equidistantly as possible. Controls were set up in an identical manner by mixing with the soil the same quantity of sand oatmeal or wheat straw but both materials were sterile omitting inoculation with *P. patulum*. Subsequent spraying with glucose solution or water and inoculation with *Phytophthora parasitica* was carried out as described above. When the seedlings emerged every seed box was watered with the same quantity of a superphosphate solution and when the first pair of leaves unfolded, boxes containing either glucose or straw were sprayed with a potassium nitrate solution in order to counteract nitrogen starvation. The results are tabulated in Table VI. The rate of emergence of the seedlings was recorded, because *Phytophthora* attacks a number of the seedlings before they emerge. In the localised inoculation set figures are quoted only for the emerged seedlings which became diseased in the sections not infected with *Phytophthora parasitica* and into which the fungus may have spread from the inoculum.

Discussion of Results

As the figures in Table VI show, the attack of damping-off was a severe one.

General Inoculation Set

The rate of emergence of tomato seedlings was higher in boxes where the antagonist *P. patulum* was present and a slight reduction in disease incidence was recorded with the exception of substratum 4, where the controls showed a lower number of diseased seedlings. The differences, however, were so small that from a practical point of view they cannot be regarded as significant.

Localised Inoculation Set

Here the presence of *P. patulum* seemed to reduce rather than increase the rate of emergence of the seedlings. It is therefore not possible to draw any conclusions from this experiment as to the effect of *P. patulum* on the rate of emergence of tomato seedlings growing in soils infected with *Phytophthora parasitica*.

The mean percentage of emerged seedlings which became diseased was lower in soils containing *P. patulum*. The highest degree of protection was found on the soil, straw and glucose substratum. This applied also to the controls though to a lesser extent. A similar observation was made in the summer of 1946 when an experiment was carried out on the control of damping-off by the antagonistic action of *Aspergillus clavatus*. In this trial the addition of glucose alone reduced disease incidence in both treatment and control. These results suggested that in addition to *P. patulum* other micro-organisms seemed to have exerted some inhibitive action on the incidence of the disease and that the development and possibly antibiotic activity of such organisms were stimulated by the addition of either straw plus glucose or glucose alone. On substratum 3 consisting of soil and straw only disease incidence was highest in the presence of *P. patulum*. No explanation but a speculative one can be given. The significance of these results is further impaired by the fact that the figures obtained from each replicate of some of the treatments showed a considerable variation. Because of the inconsistent and contradictory character of these results it is impossible at this stage to draw any conclusions or make any recommendations. When wheat straw with or without glucose is incorporated with sterilized soil and inoculated with *P. patulum* an antibiotic substance is produced under laboratory conditions and this substance does inhibit the growth of *Phytophthora parasitica*. In this applied experiment a considerably smaller amount of wheat straw was used than in the laboratory trials. It was feared that the tomato seedlings would not tolerate a large proportion of straw in the soil. The laboratory experiments were carried out on autoclaved soil while this trial had to be made on partially sterilized soil. *Aspergillus clavatus* and *Penicillium patulum* did become established on such a soil. However, it became rapidly recontaminated with the microflora of the glasshouse in which the seed boxes were incubated. This invading flora might in its turn influence the development and activity of both the specifically introduced antagonist *P. patulum* and the parasite *Phytophthora parasitica*.

Summary

1. Tests with several plant materials have shown that sugar beet pulp is a very satisfactory material for the production of an antibiotic substance by *P. patulum* and that bracken is almost as effective as wheat straw for this purpose.

2. It was found that *P. patulum* will produce an antibiotic substance when cultured on sterilized soil to which either straw or glucose or sugar beet pulp was added and that this substance inhibited the growth of *B. mycoides*, *B. carotovorum*, *B. phytophthorum*, *Corynebacterium fascians*, *Phytophthora parasitica* and *P. cryptogea*.

3. It has been shown that antibiotic activity is maintained for a considerable period in wheat straw cultures of *P. patulum*.

4. *Aspergillus terreus* and *Streptomyces antibioticus* are two other antagonistic organisms which form an inhibitory substance on wheat straw.

5. An experiment is described on the introduction of *P. patulum* into sterilized soil and its possible influence on the damping-off of tomato seedlings caused by *Phytophthora parasitica*. In the general inoculation set the rate of the emergence of tomato seedlings is greater when *P. patulum* is present and the incidence of the disease is slightly reduced with one exception. Where the inoculation with *Phytophthora parasitica* was confined to the centre of the box, fewer seedlings emerged than in control boxes, but the virulence of damping-off was somewhat reduced especially on the soil, straw, glucose substratum. Disease incidence was greatly stimulated on the straw soil medium. Owing to the great inconsistency in results no recommendations can be made.

Acknowledgments

This work has been carried out with the aid of a grant from the Agricultural Research Council.

We are greatly indebted to the following for kindly supplying the cultures used in the above reported experiments:—

Mr. W. J. Dowson for all cultures of the soft-rot bacteria and of *B. mycoides* and *C. fascians*.

Mr. L. D. Galloway for a culture of *S. antibioticus*.

Mr. George Smith for a culture of *P. patulum* and a sample of purified patulin.

Prof. S. A. Waksman for a culture of *S. griseus*.

We are also very grateful to:—

Messrs. E. E. Skillman and R. A. Engledow of the National Agricultural Advisory Service for kindly supplying us with samples of lucerne, sainfoin and mustard.

Mr. R. G. Warren of the Rothamsted Experimental Station for supplying a large quantity of very finely-ground wheat straw.

The British Sugar Corporation Ltd., Beet Sugar Factory, Felstead, for providing a sample of molassed sugar beet pulp.

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III. ANIMAL PESTS

I. THE TOMATO MOTH (*Diataraxia oleracea* L.)

By E. R. SPEYER & W. J. PARR

Introduction

THE insect known to collectors of Lepidoptera as the "bright-line brown-eye" is now generally referred to as the "Tomato Moth" on account of the serious injury which its caterpillars have caused to tomato plants grown commercially in glasshouses.

The species *oleracea* L. has in the past been placed in various genera of the family Charadriidae—such as *Hadena*, *Polia*, and *Melanchra*—but has now been assigned to the genus *Diataraxia*, of which it is the only British representative.

In 1920, Ll. Lloyd gave a comprehensive account of the life-history and habits and of the methods which he had devised for combating the pest in glasshouses. These measures for its control became a standard practice amongst growers in the great glasshouse areas of the Hertfordshire Lea Valley, and the Worthing district of Sussex.

Since that time, occasional references, chiefly to the host-plants of the insect, have appeared in Continental literature. In 1929 Zorin and Zorina published a description of the biology of the insect in the environs of Leningrad, with valuable information upon its Hymenopterous and Dipterous parasites: the life-histories and methods of breeding some of these parasites were described in greater detail by Zorin in 1927, 1930, and 1936. As all these papers are written in Russian, only general information as to their contents has been made available from abstracts in the Review of Applied Entomology.

In 1940 and subsequent years it became necessary to devote especial attention to the insect owing to the demand for the production of the highest possible yields of tomatoes in British glasshouses: it is now considered advisable to publish the information which was obtained from the literature, and to bring forward certain features of interest which have come to light during recent investigations upon the biology of the insect and of some of its parasites, which have been kept under observation at the Cheshunt Research Station.

The introduction of the insecticide DDT has led to profound modifications in the measures previously adopted for the control of the pest upon tomatoes, but it is felt that no account of the insect would be complete without some reference to the control measures devised by Lloyd, and to recommendations which have been made from time to time by Continental authors.

Economic Status as a Pest of the Tomato

In British glasshouses, the Tomato Moth appears first to have been noticed as a pest about the year 1890 at Enfield Highway, Middlesex. As the number of glasshouses devoted to the cultivation of tomatoes was increased in the neighbouring Lea Valley of Hertfordshire, so the pest spread, and became epidemic in the areas in which the nurseries were most congested. Before 1918, it had already covered the whole of the Lea Valley, representing about 1,000 acres of glasshouses, and nurseries in the Worthing District of Sussex had become severely infected, as a result either of an independent invasion of moths locally, or of transportation of chrysalids from the Lea Valley in returnable market baskets then employed in the industry. The insect was also, at this time, recorded as a pest of tomatoes in Denmark, but here the losses sustained were inconsiderable.

In 1918 the industry in the Lea Valley suffered so severely, that Ll. Lloyd was appointed Entomologist to the Cheshunt Station for the purpose of an investigation into the habits of, and control measures for the pest. He conservatively estimated the annual loss to the industry in the Lea Valley at £30,000 during the period when handpicking of the caterpillars had been the only method known for their destruction.

Through his recommendations, in 1919, for the application at suitable times of lead arsenate spray, and for the trapping of moths throughout the growing season in jars containing a sweetened poison-bait, the figure was reduced to a negligible sum, the total cost of materials employed being

about £5 per acre, as compared with a loss of not less than £150 per acre from the pest upon severely infested nurseries on which these measures were not carried out.

For more than 20 years Lloyd's methods of control remained as an established practice and were employed for infestations which occurred from time to time on the Continent (see under "Distribution and Food Plants").

In 1940, nurseries in the Lea Valley, which had previously been devoted exclusively to the cultivation of roses, were turned over to the growing of tomatoes, and upon some of these the Tomato Moth at once became very prevalent, showing that the local outdoor population of the insect had remained at a very high level.

The introduction of powders and sprays containing the insecticide DDT, the application of which, unlike that of lead arsenate, is possible at any time during the growing season, has proved so effective that the laborious method of trapping moths in jars can now be dispensed with.

Distribution and Food Plants

The Tomato Moth is widely distributed over Europe and its range extends into Asia Minor. Records show that the insect is of considerable economic importance as a pest of agricultural crops, especially in Central Europe. The caterpillars have caused severe defoliation of *Asparagus* in Germany (Dingler, 1935); Beet and Sugar-Beet in Denmark (Gram *et alia*, 1927, 1928), Czechoslovakia (Baudys, 1930; Rambousek, 1924), Central Italy (Menozzi, 1933, 1938), and Russia (Zorin and Zorina, 1929); Cabbage in Sweden (Tullgren, 1917); Mangold in South-west England (Hodson and Beaumont, 1929). Tullgren (1917) states that in Sweden 10,000 cabbage plants were destroyed in one area alone. The sporadic nature of the records indicates that outbreaks of an epidemic nature are short-lived, and that the agency of parasites as well as cool damp conditions, which are unfavourable to the successful development of the caterpillars, soon put an end to them.

Outbreaks of the pest upon a smaller scale have been noted upon vegetables, including lettuce and onion, in Austria (Wahl, 1920), Bulgaria (Buresch, 1914), Czechoslovakia (Baudys, 1930), France (Chevalier, 1930), Germany (Vogt, 1921, and Wille, 1928), and Russia (Bogdanov, 1921), upon potato in Norway (Schøyen, 1928), and upon cabbage and pea in Finland (Vappula, 1945). In orchards, defoliation of fruit-trees is recorded in Germany (Vogt, 1921) and in the Don province of Russia (Zvierezomb, 1918). Fulmek (1936) found eggs of the moth upon apple, and successfully reared the larvæ to maturity on the foliage: he also gives *Robinia pseudacacia* as a host-plant in Austria.

Other food-plants are Belladonna and Valerian in the North Caucasus (Shchegolev, 1929), Poppy in Austria (Baudys, 1930), and occasionally Chrysanthemum in Germany (Naumann, 1926).

In glasshouses, severe infestations upon tomato have occurred in the British Isles, Channel Isles, Denmark (Gram *et alia*, 1927), Holland (van Poteren, 1925, 1930), Norway (Schøyen, 1928), and Sweden (Kjellander, 1943); less important ones in Finland (Vappula, 1945).

Establishment of the pest upon more isolated nurseries in Wales and Scotland probably came about through the introduction of chrysalids transported from the Lea Valley in returnable market baskets. Local infestations originating from chance entry of moths into glasshouses have usually been confined to a single growing season, because the insect is not likely to establish itself as a permanent pest in them unless its population upon outdoor plants in their vicinity has become abnormally large. Both in Great Britain and on the Continent there are still large areas of tomato houses in which the insect has never been known to occur as a pest.

Injury caused to carnation, chrysanthemum, and cucumber is of short duration, for the caterpillars are unable to complete their development upon the foliage of these plants. The low temperatures associated with the cultivation of lettuce under glass during the winter months greatly restrict the amount of food consumed by any caterpillars which may be present, and the crop has usually been cleared before any material loss has been sustained. Under natural conditions, the insect breeds prolifically upon Goose-foot (*Chenopodium album*) a weed usually abundant in the neighbourhood of glasshouses, and the caterpillars feed also upon knotgrass (*Polygonum*), sorrel (*Rumex*), lettuce and cabbage. South (1939) records the presence of very large numbers of caterpillars upon tamarisk growing by the sea-shore.

In his experiments upon the preferences shown by the moths for certain plants upon which to deposit their eggs, Lloyd (1920) found that nearly twice as many egg-batches were laid upon white goose-foot as upon tomato. It is noteworthy that considerable numbers of eggs were deposited on bitter-sweet (*Solanum dulcamara*), upon the foliage of which Lloyd observed that the caterpillars were unable to develop, and comparatively few upon knotgrass and lettuce, the leaves of which are favourable to their development.

Life History

Under normal conditions, the life-history of the Tomato Moth does not differ materially from that of many moths commonly known as "noctuids." The moths are on the wing in June and July, or during August and early September in more northerly localities. Their span of life is about four weeks. The eggs are laid in masses on the underside of leaves, usually low down upon the host-plant, and take from 10 to 12 days to hatch. The caterpillars feed from July to September, and when full-fed after a period of from five to eight weeks, bury themselves to a depth of about an inch in the ground, where they spin a loose cocoon in which they pupate. The chrysalids hibernate, and the moths do not emerge from them until the following summer.

In glasshouses which are artificially heated early in the year for the propagation of plants, and in which temperatures are later not allowed to fall much below 52° F. during spring and autumn, the moths of the first flight may begin to emerge from the overwintering chrysalids in January, and continue to do so until the beginning of May. Eggs laid by these moths hatch in from eight to 10 days and the caterpillars, which moult five or six times during their development, may be ready to pupate, after feeding for five to six weeks, before all the moths of the first flight have emerged. Although a small proportion of the chrysalids of this first generation do not emerge as moths until July, or even until the following year, the majority do so in from three to four weeks. The first moths of the second flight appear in June and produce a second generation in which a greater proportion of the chrysalids emerge as moths only late in autumn or in the following year.

The second flight of moths is overlapped by a third, which begins in August. In heated glasshouses in southern England it thus comes about that two full generations and a partial third generation are produced annually; even in Scotland and northerly European countries two full generations are completed. Moths are therefore present in heated glasshouses practically throughout the year. As a result, the insect quickly becomes abnormally abundant, and the vastly augmented numbers of moths which escape from infested glasshouses during the summer months, when doors and ventilators may be kept open during the whole day and night, lead to a great increase in the population of the insect upon weeds and other suitable host-plants in the immediate vicinity. Evidence of the rate at which the pest increased when routine measures for its control were temporarily suspended, was afforded by records taken of the number of moths trapped by means of moth jars in the two propagating houses at the Cheshunt Station. Normally these glasshouses carried a tomato crop after propagation had ended in each season, and the pest was controlled by lead arsenate spraying and moth trapping. In 1943, however, tomato seed was sown thickly on benches for a special purpose, and the dense cover of unsprayed foliage later provided an ideal breeding ground for moths which entered the houses from outside. In Table I records of capture are given for each year from 1940 onwards; the enormous rise after August, 1943, is self-explanatory, and was followed by a proportional increase of moths which emerged from overwintered chrysalids in the soil during the propagating period of 1944.

TABLE I
INCREASE OF MOTHS AFTER SUSPENSION OF CONTROL MEASURES

Year	Period	Moths	Nº. per Jar
1940	19.ii-2.v	47	4.0
1941	29.i-5.iv	110	6.9
1942	19.i-11.v	55	4.6
	11.viii-30.ix	3	—
1943	12.i-12.v	18	1.5
	12.viii-1.x	613	51.1
1944	20.i-16.v	159	13.3

The Moth

The sombre-coloured moths, the sexes of which closely resemble one another in colour and size, are illustrated in Plate II, Figs. 7 and 8. They have a wing expanse of $1\frac{1}{4}$ to $1\frac{3}{4}$ ins.; the forewings are dark, reddish, or purplish brown, with a characteristic jagged sub-terminal white line; the "stigmata" are faintly outlined with white, the orbicular being yellowish brown and larger than the reniform stigma. The hind-wings are greyish and often more or less deeply shaded round their hind margins. But little variation in colour has been observed amongst very large numbers of

specimens collected from glasshouses; moths bred from caterpillars obtained upon a nursery in Lanarkshire, Scotland, showed no appreciable difference from those found in the south of England. Hampson (1909) has described and figured a remarkable aberration of the moth caught at sugar at Aberdeen in July, 1900; this insect was so different in colour and appearance from the normal form that he described it as belonging to the new genus and species, *Peucephila essoni*.

During daylight, the moths hide away usually in crevices in the ground; they do not lodge upon fences and, unlike so many of their allies, are but rarely attracted to light at night. They are therefore seldom observed even in localities in which they are especially abundant, and in glasshouses are usually only noticed when they are disturbed, especially when the ground is being watered: when so disturbed the moths make short and rapid flights. Wings of the insect, which had been detached by bats, were found early in the morning on roadways in Northumberland in September, 1947.

The males are polygamous and are considerably outnumbered by the females.

Both sexes are attracted at night to sweet and slightly fermenting substances.

By the use of jars hung from the wires of tomato houses and containing a mixture of ale and treacle, to which a small quantity of sodium fluoride had been added as a poison, Lloyd (1920) was able to obtain large numbers of moths and to determine the proportion of the sexes.

Out of 1,230 moths so trapped, 29 per cent. were males and 71 per cent. females. Again he records (loc. cit. p. 96) that of 3,025 moths caught upon a commercial nursery from July to September inclusive, approximately 71 per cent. were females.

Over a period of four years, from 1940 onwards, the moths similarly trapped in the experimental tomato houses at Cheshunt were sexed, and the proportions are seen in Table II:—

TABLE II
PROPORTION OF THE SEXES

Year	Period	Males	Females	Total	% Males	% Females
1940	19.ii-4.v	75	134	209	36	64
1941	29.i-8.v	94	130	224	42	58
	13.viii-12.xi	5	23	28	—	—
1942	19.i-11.v	96	185	281	35	65
	11.viii-30.xi	7	15	22	—	—
1943	12.i-12.v	118	230	348	34	66
	12.viii-1.ix	152	257	409	37	63
Total		547	974	1521	36	64

Of 211 moths trapped upon commercial nurseries in the Cheshunt district between April 9th and May 19th, 1941, 37 per cent. were males and 63 per cent. were females.

It would therefore appear that a rise of about 7 per cent. in the proportion of males has taken place during the odd 20 years intervening between the periods at which these records were obtained.

Moths which are present in glasshouses become active at dusk, and because of their apparent dislike for the humid atmosphere, beat against the glasspanes along the sides which receive most light, in their endeavour to escape. They tend, therefore, to fly towards the western sides of blocks of houses, and to collect at their southern ends and particularly at their south-west corners. Ample evidence of this is forthcoming from a comparison of the numbers of moths trapped in jars placed in various positions in the houses.

Out of 2,400 moths trapped by Lloyd (1920) over a long period in equal numbers of jars placed along the north and south ends of a block of 12 glasshouses, 40 per cent. were caught in those at the north, and 60 per cent. in those at the south end. In 1941, almost exactly similar percentages were obtained in moth-trapping experiments, though in these the total number of insects caught was far smaller, in the region of 200.

Here, also, comparison was made between the numbers caught respectively along the east and west sides of blocks, and out of a total of 239 moths, 78 per cent. were obtained in jars along the west sides. Lloyd (1920) caught more than twice the number of moths in the trap placed at the south-west corner of a block of 12 houses than the average number for all the jars evenly distributed throughout the block. In 1941, at least three times the average number were obtained at the south-west corner of blocks of houses in the Cheshunt district, except in one instance, when the south-west corner was shaded by buildings, and only four moths were caught here as compared with 14 at the south-east corner (See Speyer and Parr, 1941, p. 56.). By means of an elaborate method of screening

Lloyd (1920) proved that moths were not attracted from outside to traps set within glasshouses, and computed that the radius of attraction to a sweetened bait was about 40 ft.

Moths kept in the laboratory by Zorin and Zorina (1929) lived for a period of about four weeks. Lloyd (1920) showed that both sexes when provided with broken ripe tomato fruit as a source of nutriment lived about twice as long as those from which all food was withheld, but which had access to water.

Still more striking was the effect of lack of food upon the fecundity of the female, as illustrated from his experiments. The average number of egg batches deposited was reduced by half, and the average number of eggs in each batch by one-third; this represents a decrease of 70 per cent. in the total number of eggs laid by unfed moths.

Mating may take place soon after the wings become fully expanded, but the female does not begin to oviposit until the second or third day after emergence from the chrysalis.

The eggs are practically always deposited upon the under-surface of leaves, and nearly always in batches of considerable size. The first-laid eggs of a batch are arranged in regular rows of four upon the leaf surface (Plate I, Fig. 1a) and after some 9 to 12 rows have been completed, more are added in less orderly manner on top of them and at the periphery. Lloyd (1920) gives the average number of batches laid by a single female as about 11, the average number of eggs in each as about 66 (with a maximum of over 300) and the total number of eggs as nearly 900 for moths kept and fed in cages. Under more natural conditions, over 1,000 eggs may be produced by a single moth (Zorin and Zorina, 1929).

The Egg

(Plate I, Fig. 1)

The egg is hemispherical with the dome slightly depressed and the transparent shell strongly ribbed and reticulate except for the floor which is flat and smooth: it has a diameter of about 0.75 mm. When newly laid it has a greenish colour, but the contents soon become pale yellow or almost white ((Fig. 1 (a)), and upon the fourth day of incubation at room temperature a small spot near the summit of the dome indicates the beginning of sclerotisation of the larval head. On the fifth day, greyish patches make their appearance and the dark setae of the larva become visible within the shell. By the eighth day (Fig. 1 (b)) the egg has become uniformly suffused with purple, the larval head-capsule is fairly strongly sclerotised, and the setae arising from black dot-like scleroites are seen to change position when the larva moves within the shell. From dissections made of eggs in different stages of development (Speyer and Parr, 1944, p. 39) it was concluded that the purple colour is due to the presence of dark granules which make their appearance in the fluid surrounding the larva; probably these granules are products of excretion voided by it. Lloyd (1920) attributed the dark colour to entry of air through the shell shortly before hatching of the larva. Some 12 to 18 hours after the egg has become uniformly dark, the larva hatches by cutting, usually in the side of the dome, a circular piece of shell which it devours before making its exit. Air now enters the white and transparent shell, the greater part of which is usually also eaten by the young caterpillar. All the eggs of a batch hatch more or less at the same time or within a few hours of one another. The incubation period of eggs kept in the laboratory at temperatures ranging from 56° F. to 83° F. in April, 1944, was 8 to 10 days. Zorin and Zorina (1929) give eight days at 68° F. and 10 to 12 days in the field for the period of incubation, and Lloyd (1920) seven to eight days at temperatures varying from 67° F. to 80° F.

The Larva

(Plate I, Fig. 2; Plate II, Figs. 3-5)

(1) Influence of Food upon Development

Were even a moderate proportion of larvæ from every egg-batch to survive, the available food-supply within the confines of glasshouses would inevitably become exhausted within a very short period of time.

One factor which to some degree limits the number of caterpillars is a high mortality amongst the 1st instar larvæ when they disperse to the surrounding foliage from the leaflet upon which the egg-mass was deposited, and again when the 3rd instar larvæ travel further afield and appear to encounter difficulty in climbing the stems of tomato plants.

Lloyd (1920, pp. 72-77) was seldom able to rear the caterpillars upon an unvaried diet of tomato foliage. He carried out many experiments, the results of which may briefly be summarised:—

- (1) Usually one or two larvæ only from each egg-mass were able to complete their development, and in but one instance were the majority able to do so, when fed exclusively upon tomato foliage.
- (2) Caterpillars which had reached the point of starvation upon, or which were collected from, tomato foliage, grew rapidly and completed their development when provided with that of *Chenopodium* or of other suitable plants.
- (3) Many larvæ which were reared from the egg upon *Polygonum* and *Chenopodium* and transferred, when two to three weeks old, to tomato, made growth but were unable to complete their development.
- (4) Although the great majority of larvæ completed their development upon an unvaried diet of *Chenopodium*, a very small number from some egg-masses were unable to do so. Larvæ from eggs deposited upon *Solanum dulcamara* and provided only with the foliage of this plant never survived.

Lloyd suggested that the high mortality amongst caterpillars fed exclusively upon tomato foliage might be due to the presence of poisons, to which certain individuals were immune, contained in Solanaceous plants, but considered it more probable that tomato foliage was deficient in some substance essential to their successful development.

At the time at which these observations were recorded, the tomato variety Comet was grown almost exclusively upon commercial nurseries, and the foliage of this variety was, in fact, employed in Lloyd's experiments. During the period July to October, 1938, large numbers of larvæ were reared in connection with the breeding of a parasite, and although some were fed upon a mixed diet of tomato variety E.S.1 and *Polygonum*, a great number completed their development normally when supplied only with the foliage of this variety. More recently, no difficulty has been encountered in rearing the caterpillars upon an unvaried diet of several of the more modern varieties, including E.S.1 and Potentate at various times of the year.

Larvæ reared from the egg in the laboratory at a mean temperature of 66° F. during April, 1944, completed their development in from 33 to 39 days upon an unvaried diet of the variety Potentate (as compared with a duration of 37 to 44 days on Comet and 28 to 31 days on *Chenopodium* or *Polygonum* recorded by Lloyd); these caterpillars were given the opportunity of feeding also upon *Polygonum*, but they showed a marked preference for tomato, and the leaves of the former plant remained practically untouched by them. Speyer and Parr (1946, pp. 50-51) successfully reared caterpillars of all ages, from the 1st instar to the 6th, collected from tomato plants in the experimental glasshouses at Cheshunt, exclusively upon the foliage of the varieties Comet and Potentate; the degree of mortality amongst them was quite insignificant, and it was suggested that, through gradual selection over a number of years there might have arisen in the locality a race of the insect in which the caterpillars had become resistant to the action of some poisonous substance contained in the foliage of the tomato plant.

(ii) Habits

Larvæ in the first and second instars feed gregariously upon the leaf-surface, which becomes skeletonised (Plate I, Fig. 2); when disturbed they suspend themselves upon threads. After the second ecdysis has been completed, they disperse, and devour larger areas of the foliage together with the leaf-veins. Later they eat into the stems and fruit, and, when full-fed, bury themselves to a depth of 1 to 4 ins. in the ground according to the nature of the soil. For a period of 12 to 24 hours before each ecdysis, the larva ceases to feed, and after each, except the last, the moulted skin, save for the head capsule, is devoured. During the ecdysis the larva is firmly fixed to the leaf-surface by the prolegs, and at any rate in the later moults, strands of fine silk spun along the ventral surface of the body give extra support.

Very moist conditions are unfavourable to development, and when they are ready to pupate, the caterpillars prefer to spin their loose silken cocoons in crevices in the glasshouse structure, in hollow plant-canes, or in dry dead leaves, rather than bury themselves in wet clay soils. They will even hollow out grooves in dry woodwork, particles of which become incorporated in the cocoons. After the cocoon is completed, there is a diapause extending over a period of some days, and when the final ecdysis is completed, the moulted larval skin envelopes the posterior extremity of the pupa.

(iii) Description of the Instars (Plates I and II, Figs. 2-5)

The following brief descriptions of each larval instar were made from a few caterpillars kept in the laboratory during April, 1944, and are representative of larvæ of the first annual generation. In

general the prevailing colour of the later instars is exceedingly variable as noted by Lloyd (1920, p. 71).

In all instars the transverse rows of dark setæ arise from black dot-like sclerites: in the earlier ones, the colour of the head is pale green. The spiracles upon the prothorax and first eight abdominal segments become conspicuous in the third instar, those upon the prothorax and eighth abdominal segment being the most prominent; each is oval in shape, and the white peritreme is encircled with a black ring.

First Instar.—Length on hatching, 3.0 mm. Shiny dark green dorsally, yellowish green laterally and ventrally. The chaetotaxy is illustrated in text—fig. 1.

Second Instar.—Length at first ecdysis, 4.5 mm. Green, with three indistinct longitudinal broken white stripes dorsally.

Third Instar.—Length at second ecdysis, 6.0 mm. Green, the three dorsal white stripes more conspicuous, a distinct yellow longitudinal stripe laterally on each side.

Fourth Instar (Plate II, Fig. 3).—Length at third ecdysis, 9.0 mm. Pale to dark green, the integument densely and minutely speckled with white. Dorsal white and lateral yellow stripes as in previous instar.

Fifth Instar.—Length at fourth ecdysis, 11–16 mm. As previous instar, but the yellow lateral stripe is bordered along its upper edge by a faint grey stripe.

Sixth Instar (Plate II, Fig. 4).—Length at fifth ecdysis, 15–25 mm. Yellowish green to yellowish or reddish brown, the three dorsal stripes partially obliterated by underlying greyish-black stripes; the grey stripe along the upper edge of the lateral yellow stripes more conspicuous. Intersegmental areas of green larvæ bright yellow, of darker ones reddish brown.

Seventh Instar.—Length at sixth ecdysis, 29–35 mm. Yellowish or reddish brown; the three dark grey dorsal stripes more conspicuous, lateral yellow stripes as in previous instar. Head almost white to light or greyish brown, with marbled areas (text—fig. 2); the six ocelli of each side arranged as in text—fig. 3. Prothorax, in the anterior portion a setigerous black spot laterally on each side, not contiguous to the spiracle. Meso—and metathorax each with two setigerous black spots on each side. First to seventh abdominal segments upon each, two black spots, devoid of setæ, one anterior and one posterior to the spiracle of each side. Eighth and ninth abdominal segments—laterally in the posterior portion of each, a setigerous black dot: tenth abdominal segment devoid of dark spots or dots.

When full-grown the larva has attained a length of $1\frac{1}{2}$ to $1\frac{3}{4}$ ins. (Plate II, Fig. 5).

(iv) Duration of the Instars

Though the normal number of larval instars would appear to be seven, a very considerable number of larvæ are in their final instar after only five ecdyses. Such larvæ assume the colouration of the seventh instar at the fifth ecdysis, and the sixth instar is missed; these larvæ appear to spend a rather longer period of time in the fifth instar.

Lloyd (1920, p. 77) has shown that under normal conditions in tomato houses the average duration of the larval life lies between 35 and 45 days, but that period was reduced to as little as 20 days at a mean temperature of 72° F. when foliage of *Polygonum* was provided.

In Table III the duration of each instar observed for five larvæ of the first annual generation is given; the larvæ were kept at room temperature* in April, 1944, and were fed upon tomato foliage from young plants, which was preferred to that of *Polygonum*.

* The recorded temperatures were: Mean, 66.5° F.; mean max., 70° F.; mean min., 63° F.; range, 59° F–77° F.

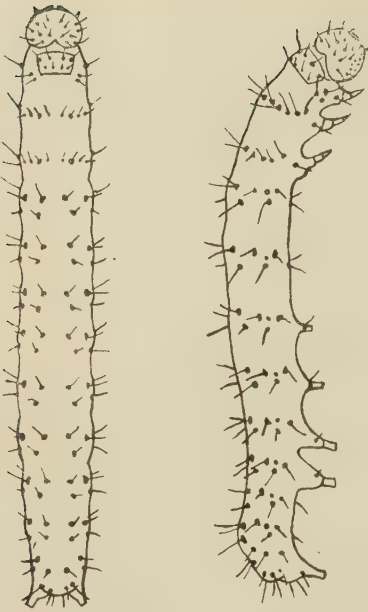
TABLE III
SPRING BROOD. EGGS HATCHED MARCH, 26TH, 1944

Larva No.:	Duration of Instars in Days					
	1	2	3	4	5	Av.
First Instar	5	7	7	5	6	6.0
Second Instar	5	4	5	4	4	4.5
Third Instar	6	4	6	4	4	5.0
Fourth Instar	5	4	4	5	5	4.5
Fifth Instar	4	5	3	7	6	5.0
Sixth instar	5	5	4	9	8	6.0
Seventh Instar	9	6	8	—	—	8.0
Total	39	35	37	34	33	36.0

From the characters of the pupæ, it was ascertained that all five larvæ were of the female sex.

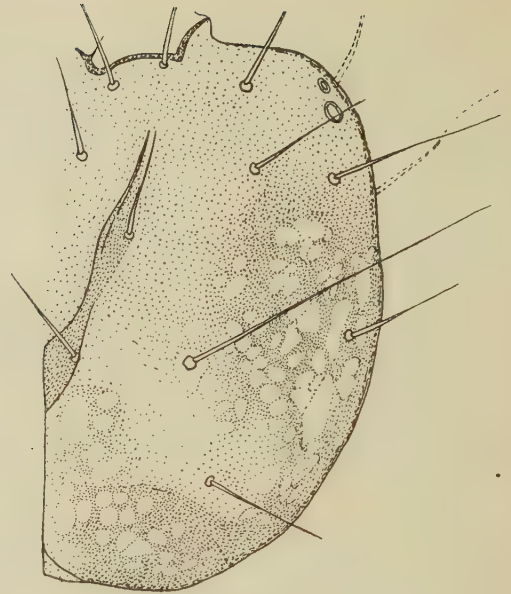
(v) Number of Ecdyses

Measurements of the moulted head-capsules of these five larvæ are given in Table IV. Those of Nos. 1, 2, and 3, which pupated at the seventh ecdysis conform closely to the calculated measure-



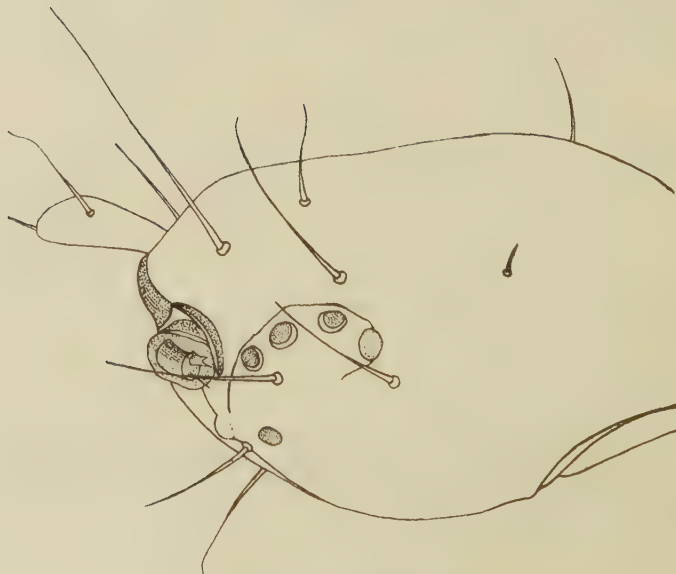
Text—fig. 1

Larva, 1st instar x 20 (after Zorin and Zorina, 1929).



Text—fig. 2

Full-grown larva x 25. Right half of head capsule in dorsal aspect.



Text—fig. 3

Full-grown larva x 25. Lateral view of head capsule, left side.

ments in accordance with the principles of Dyar's law, and it would therefore appear that the normal number of instars is seven.

TABLE IV
MEASUREMENTS IN MM. OF BREADTH OF CAST HEAD-CAPSULES
Average ratio of increase for larvæ Nos. 1, 2, and 3=1.44

Instar	Calculated	No. 1	No. 2	No. 3	No. 4	No. 5
First	—	0.38	0.40	0.38	0.37	0.38
Second	0.55	0.56	0.56	0.56	0.51	0.55
Third	0.79	0.77	0.75	0.76	0.87	0.85
Fourth	1.14	1.06	1.08	1.16	1.18	1.26
Fifth	1.64	1.55	1.52	1.61	1.89	1.86
Sixth	2.36	2.37	2.26	2.31	3.07	3.45
Seventh	3.40	3.65*	3.30	3.35	—	—

* On recovery from the cocoon, this capsule was somewhat distorted.

The head capsules of first instar larvæ from other sources were found invariably to measure 0.38 mm. in breadth; it is from this measurement, which is also the average for the five cast capsules in the table, that the calculated figures are computed.

The Pupa

(Plate II, Fig. 6)

The pupa is at first brown, but soon becomes of a shining black colour; it measures about $\frac{3}{4}$ in. in length. The cremaster terminates in a pair of cylindrical organs each about 1 mm. long and expanded at its extremity so as to resemble a funnel. As in other Lepidoptera, the sex of the pupa is readily determined from the character of the ventral surface of the posterior abdominal segments, and the position of the genital aperture upon them, as illustrated in text—figs. 4 and 5.

(i) Duration of the Pupal Instar

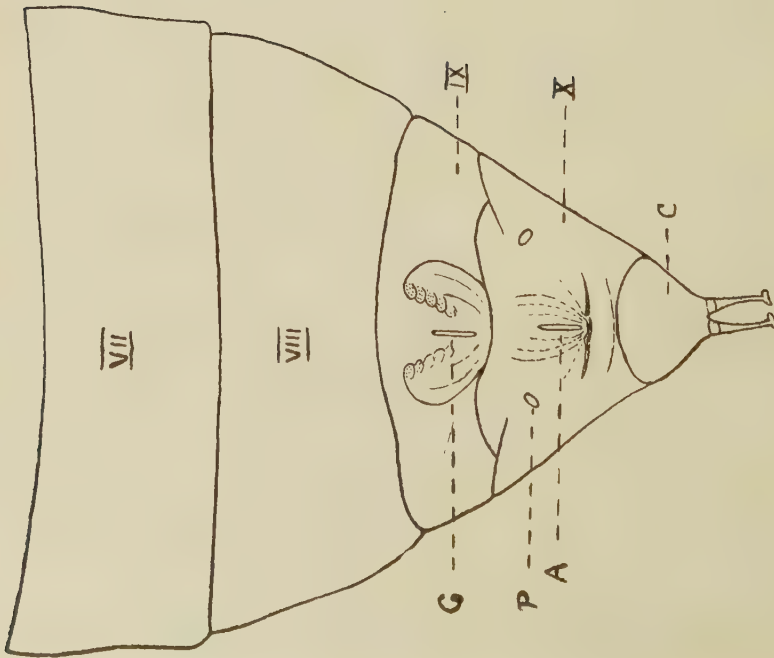
Lloyd (1920, pp. 77-81) observed great variation in the duration of the pupal instar, and was able to separate the pupæ into two categories—those of the short-period type which emerged in from 16-50 days, and those of the long-period type which emerged only after from 100 to as many as 300 days. He found that the short-period type was most prevalent in May and June and that the proportion of long-period pupæ increased from July onwards until in later autumn all were of the latter type. Pupæ which he obtained in April were again all of the long-period type. He demonstrated experimentally that the period of pupation was influenced only to a slight extent by varying the conditions of temperature. Pupæ which he obtained from July to September were kept in a heated greenhouse at a mean temperature above 60° F.; they proved to be all of the long-period type and the moths emerged from them from the middle of December until May, the majority during February, March, and April.

Zorin and Zorina (1929) reared larvæ at a mean temperature of 80.6° F.; from the pupæ obtained, the moths emerged in from two to three weeks. Some of the pupæ were kept at temperatures of 50°-53.6° F. at which they continued to develop, and moths emerged from them soon after they were brought into a warm environment.

On May 13th, 1943, 10 full-fed caterpillars were received from tomato houses in Lanarkshire, Scotland; they entered the soil to pupate within four days, and were kept in the laboratory at Cheshunt. Moths emerged from them after respectively 26, 67, 80, 103, 129, 131, 133, 134, 137, and 166 days. Thus one pupa only was of the short-period and seven were of the long-period type. It is of interest that the two remaining pupæ fell between these, showing that intermediates may occur, at least in a very northerly locality.

The periods of the pupæ obtained from the five larvæ kept under observation at Cheshunt (see Tables III and IV) are shown in Table V; from April 28th to September 23rd the recorded temperatures were: Mean, 65.6° F.; mean max., 69.5° F.; mean min., 61.8° F.; range, 54°-83° F. All the pupæ were females.

Although both larvæ and pupæ had been kept under exactly similar conditions in the laboratory, only one pupa (No. 5) was of the short-period type, and amongst the long-period pupæ there was remarkable variation. Ample evidence is therefore forthcoming, that the duration of the pupal

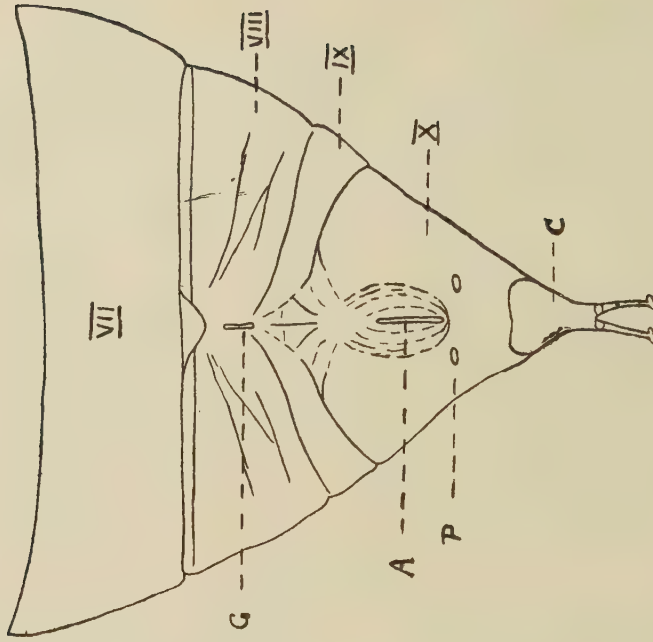


Text—fig. 4

Male pupa x 16.

Posterior abdominal segments in ventral aspect.

A.—Anus. C.—Cremaster. G.—Genital aperture. P.—Papilla.
 VII-X.—Abdominal segments.



Text—fig. 5

Female pupa x 16.

Posterior abdominal segments in ventral aspect.

A.—Anus. C.—Cremaster. G.—Genital aperture. P.—Papilla.
 VII-X.—Abdominal segments.

TABLE V
DURATION OF PUPAL INSTAR. SPRING BROOD, 1944

Pupa from Larva No.	Larva entered Soil	Moth emerged	Duration in Days
1	4.v	3.xii	213
2	30.iv	22.x	175
3	2.v	10.i.45	253
4	29.iv	23.ix	147
5	28.iv	23.v	25

period is determined by an innate factor which is not influenced to any material degree by external conditions. A rise in temperature certainly induces emergence if the moth within the chrysalis case has previously become fully developed, and emergence may occasionally take place at comparatively low temperatures, for on December 9th, 1944, a living moth was found in a glasshouse, in which the temperature during the previous six weeks had certainly not risen above 50° F.

Nature of Injury caused to Plants

(Plates III and IV)

Since the moth usually lays its eggs in batches of from 50 to 150 on a tomato leaflet, and all the eggs hatch within a few hours of one another, large numbers of caterpillars come to be situated within a very limited area of leaf-surface. At first the young caterpillars devour the epidermis of the underside of the leaflet upon which they have hatched (Plate III, Fig. 9), but when this has become entirely skeletonised, and only its dry framework remains, they move to new leaflets in the immediate vicinity. Here they form smaller colonies and eat out irregular rounded holes in them.

Not until some 10 days after hatching do they abandon their gregarious habit and disperse to considerable distances from their original habitat. They now eat larger holes in the foliage and may devour large portions of individual leaflets, but it is not until they have attained a length of $\frac{3}{4}$ in. or more that they begin to cause any severe injury to tomato plants. Two or three caterpillars of this size are capable, within a night, of completely stripping the leaflets from several leaves, so that little remains but the bare leaf-stalks. The greatest amount of injury is caused during the last fortnight or three weeks of the caterpillars' life, when they acquire a habit of eating into and tunnelling in thicker portions of the main-stem, which thus becomes highly liable to fracture (Plate III, Fig. 11). Finally they will eat large holes in the fruit, both when it is green and when it is ripening (Plate III, Fig. 10).

Less frequently and usually in February, moths may be present in cucumber houses in which tomatoes have been grown during the previous autumn. Skeletonising of leaves by the newly-hatched larvæ may cause some alarm to the grower, but the caterpillars do not survive beyond the stage at which they begin to eat larger holes in the leaves, as the foliage of cucumber does not provide them with nourishment suitable for their further development.

From time to time damage by the caterpillars to carnation plants has been recorded in the large tomato-growing districts of southern England in which the pest had become well established. More unusual are records relating to injury upon a nursery in Hampshire during late September, 1926, and on one in Cornwall in July of 1937 and 1938, both situated in districts where infestations upon tomato were practically unknown. In the latter instance, full-grown caterpillars had severed leaves and gnawed out portions of the calyx of flower-buds (Plate IV, Fig. 12) and in the former had devoured petals of open blooms (Plate IV, Fig. 13).

In July, 1937, at the Cheshunt Station, numbers of moths were liberated in an experimental glasshouse containing carnation pot-plants; no egg-masses were found subsequently upon the foliage, but the presence of isolated caterpillars suggested that the moths had deposited their eggs singly or at most in very small groups, the narrowness of the leaves having prevented them from ovipositing in the normal manner. The young caterpillars removed tissue from the upper side of the leaves (Plate IV, Fig. 14) and when about $\frac{1}{2}$ in. long ate shallow holes in the underside (Plate IV, Fig. 15).

Methods of Control

Since Lloyd (1919) first published his recommendations for the control of Tomato Moth, no alternative measures of any true practical value for combating the pest had been devised until

dusting powders and spray fluids containing the insecticide DDT became available for use in 1944.

During the intervening period, Lloyd's methods had proved effective in so far as they could be relied upon to prevent any serious loss of crop to the grower, but they could not entirely obviate the outbreak of severe infestations upon tomato plants during late summer and autumn in districts in which the pest had become well established. These infestations arose principally as a result of moths accidentally entering the glasshouses from outside at a time when application of insecticides over large areas was inconsistent with economic practice. (The idea, advanced by Kjellander (1943), of screening ventilators and doors to prevent access of moths to glasshouses, involves great expense and doubtless also loss of crop due to the cutting off of light and ventilation.) Further, there had been discovered no really effective insecticide which could be applied to plants in bearing without the risk of tainting the fruit.

DDT has not only fulfilled that requirement, owing to the rapidity of its lethal action—an asset which renders it effective when applied within limited areas in which the presence of caterpillars has been detected—but, as a residue upon the foliage, retains that action for long periods of time after application. So effective has this insecticide proved to be, that the laborious methods of trapping caterpillars and moths, which had been essential adjuncts to early spraying with lead arsenate, can now be dispensed with. Lead arsenate sprays are, however, still useful for application to tomato plants up to a height of 4 ft. when suitable apparatus for the distribution of dusts is not available, and to certain types of plants (including cucumbers) to which DDT cannot be applied without risk of injury to the foliage.

(1) Control by Means of DDT

(a) Methods of Application

In a preliminary report issued by the Cheshunt Research Station (Circular No. 17, April, 1946) upon the use of DDT for the control of the pest on tomatoes, the following recommendations were made: Upon nurseries in the glasshouses of which there is reason to suspect the presence of moths early in the year, a 5 per cent. DDT dust should be applied about 10 days before the plants will be removed from the propagating houses, followed by a second application about one month after planting out in the ground. A very light application to the upper surface of the foliage, and involving the use of about 15 lbs. dust to the acre, is desirable.

To obtain good distribution, and to obviate heavy deposits of powder upon the rows of plants immediately adjacent to the paths of the glasshouses, an extension should be fitted to the dusting machine, if the rotary type of hand-blower is employed, the delivery pipe being directed upwards so that the dust is blown above the head of the operator, while he walks backwards along the path.

Until the plants have attained a height of about 4 ft., the application of dusts is more economic than that of sprays, which may also cause some injury to the foliage of young tomatoes.

Should they occur upon the plants later in the growing season, the caterpillars may be destroyed by application of sprays containing DDT, either in suspension or emulsion, at a concentration of one part pure DDT in 5,000 parts water. Such sprays need be applied only to the upper surface of the foliage. As the residue left upon the foliage remained poisonous to the caterpillars for a long time, it was found necessary upon some commercial nurseries to spray only once in order to keep the plants free from infestation during the remainder of the growing season.

(b) Effect upon the Eggs

Speyer and Parr (1944, p. 38) recorded that 79 per cent. of the caterpillars hatching from egg-batches to which a 5 per cent. DDT powder had been applied at periods of from two to seven days after deposition by the moths, died in the process of escaping from the egg-shells; the remaining 21 per cent. hatched successfully. The degree of mortality obtained was dependent upon the depth of the individual egg-mass, and not upon the age of the eggs at the time of treatment.

From further experiments (*loc. cit.*, p. 39), in which sprays containing DDT in emulsion at concentrations ranging from 0.013 per cent. to 0.05 per cent. were applied to egg-batches at periods of from four to nine days after their deposition, from none of which caterpillars completed the process of hatching, it was concluded that DDT penetrated the egg-shells in quantities insufficient to prevent development of the larva, but sufficient to enfeeble it to a degree which prevented it from perforating the shell.

Caterpillars in eggs situated more deeply within, or in those forming the floor of a batch were able to perforate the shell, but died before making their escape, possibly as a result of ingesting the insecticide adsorbed upon the surface of the piece of shell which they had devoured.

(c) Effect upon the Caterpillar

Read (1944, pp. 54-56) applied a kaolin powder containing 5 per cent. DDT to tomato plants upon which caterpillars of all ages had been placed; within a few hours all had fallen to the ground whence they were unable to regain access to the plants. The larger caterpillars were capable of movement up to 48 hours, but even when removed to fresh foliage three hours after application of the dust, they died without attempting to feed. Full-grown caterpillars placed upon the foliage of the dusted plants 12 days after the application succumbed, and newly-hatched larvæ died when placed upon foliage which had been dusted 20 days previously. Sprays containing DDT (in emulsion) at a concentration of .02 per cent. killed the caterpillars in all stages of their development, and their lethal effect upon fourth instar larvæ persisted upon the foliage for a period of at least six days; a concentration of 0.007 per cent. was sufficient to destroy newly-hatched caterpillars.

Small quantities of a powder containing 5 per cent. DDT were applied by means of a fine brush to the exposed portions of the dorsal cuticle. Of three larvæ in the second instar so treated, two had died and one was in a moribund condition after a period of 16 hours; four larvæ in the third instar were moribund after a similar period. No effect, however, was produced upon a larva which had moulted four days previously to the sixth instar, but when a larger quantity of powder was brushed over the whole dorsal surface, the caterpillar became paralysed within 24 hours, and died within 48 hours after the application. It is possible, therefore, that DDT gained access to the internal tissues of the older larva through thinner portions of the cuticle, which occur at the sutures between the segments.

(2) Lloyd's Method of Control on Tomato Nurseries

In devising his control measures, Lloyd (1920) aimed at the destruction of the pest in all phases of its life-history, and especially at preventing, as far as possible, the escape of moths from infested tomato houses with a view to obviating increase of the pest outside in their immediate vicinity.

These methods involved destruction of the caterpillars by spraying, early in the growing season, with lead arsenate; by trapping the caterpillars after spraying had become impracticable; by trapping the moths throughout the growing season; by destroying the chrysalids in the soil after termination of the crop; and by general precautions relating to the destruction of weeds within and outside the glasshouses, the collection of any fallen fruit liable to rot on the ground, and the setting aside of special market baskets for use in fruit-picking.

General improvement in nursery management subsequently rendered the latter precautions unnecessary, and the ever-extending practice of soil sterilisation by steam dispensed with the laborious method of destroying chrysalids in the soil during the winter months; further reference to these precautions may therefore be omitted.

(a) Spraying with Lead Arsenate

As a stomach poison for the destruction of the caterpillars 2½ lbs. lead arsenate paste or from 1 lb. to 1½ lbs. lead arsenate powder are stirred to a thin cream with about 1 pint water, in which 1 ounce saponin has been dissolved; this amount is sufficient for addition to the water with which a 40-gallon capacity spraying tank has previously been filled. The saponin keeps the lead arsenate in suspension for a considerable time, but the tank should be provided with an agitator.

(i) Method and Time of Application

The spray is applied to the upper surface of the foliage only, and not heavily enough to produce excessive dripping from the leaves. Spraying during periods of sunlight is advantageous, because the residue dries quickly upon the foliage. Being insoluble in water, the compound does not injure the leaves of plants. Three applications are necessary, the first to pot-plants in the propagating houses, the second a week after the plants are set out in the ground, and the third, which is the most important, two weeks before the fruit begins to swell upon the lower trusses. Owing to its poisonous nature, the spray must not be applied later in the growing season when ripening fruit is present upon the plants.

(ii) Effect upon the Caterpillars

In February, 1940, nine tomato plants upon which 22 caterpillars in the third instar were feeding, were sprayed with a concentration of lead arsenate, in colloidal form, equivalent to 3 lbs. to 100 gallons water; 17 hours later five larvæ were dead and seven in a moribund condition; on the second day seven remained alive, and all had died by the fourth day after application.

Lloyd (1920, p. 89, Table VI) sprayed plants with different concentrations of lead arsenate paste, ranging from 2 lb. to 10 lbs. to 100 gallons water, and when the foliage had dried placed upon

it large numbers of half to full-grown caterpillars. The figures given in his table show that the rate at which the caterpillars died was in inverse proportion to the amount of lead arsenate contained in the spray fluid; at the lowest concentration some survived until the thirteenth day, and at the highest only until the sixth day after application. The number of caterpillars which pupated during the experiment was not significant.

There was not a sufficient difference between the effects of a concentration of 6 lbs. and one of 10 lbs. lead arsenate paste, to the 100 gallons water, to warrant the use of the higher concentration in practice, but at concentrations below 5 lbs. considerable injury was caused to the foliage from feeding of the caterpillars before they had taken a fatal dose.

As pointed out by Lloyd, the residue of lead arsenate left upon sprayed foliage is distasteful to the caterpillars and a large proportion of them, after ingesting a sub-lethal dose, may cease feeding until hunger drives them to take a fatal one.

When poisoned by lead arsenate, the caterpillars become lethargic and no peculiar external symptoms are shown, further than a flabbiness of the skin, due doubtless to relaxation of the muscles (Plate V, Fig. 17).

(b) Trapping of Caterpillars

When the full-grown caterpillars have ceased to feed they will travel far in order to find suitably dry and sheltered places in which to spin their cocoons before they turn to chrysalids. In so doing, they tend to move towards the ground, and can be intercepted by means of loosely folded sacking slung over the hot-water pipes under the gutters, and over the lower supporting wires so as to be in contact with the woodwork of the glasshouse.

By distributing 11 sacks in three tomato houses during September, Lloyd (*loc. cit.*, p. 93) trapped 729 caterpillars during a period of three weeks (Plate V, Fig. 16).

The caterpillars and any chrysalids to which they may have turned, are destroyed by dipping the sacking for half a minute in a cauldron of boiling water. To avoid possible emergence of moths from the chrysalids and unnecessary labour in collecting and dipping the sacks too frequently, the operation should be repeated on every twenty-first day after the sacking has first been placed in position.

The practice is most applicable after severe infestations of caterpillars have developed during late summer and early autumn.

(c) Moth Trapping

After emergence from the chrysalids, one of the first instincts of the moth, whether male or female, is to seek nourishment in liquid form. The moths are strongly attracted to a mixture of beer and treacle, or other sweet substance of somewhat similar nature, but only slightly to either of these alone. Female moths will visit such a bait before they have begun to lay eggs, or at least before they have deposited many (see Lloyd, 1920, p. 95; Speyer and Parr, 1941, pp. 55-56).

The most practical form of trap, in which to secure them, is a glass jar with a mouth not less than 2 ins. in diameter (a half to one pound jam-jar is suitable), into which about 3 fluid ounces of the bait have been introduced.

Moths attracted to the bait often fall into the liquid and are unable to escape, but their dead bodies provide a platform for later visitors, and it is therefore necessary to add a small quantity of a suitable poison which will kill those which may fly away after feeding, and to remove dead moths from the jars at weekly intervals.

Sodium fluoride poisons the moths and largely prevents the formation of scum upon the bait, but evaporation necessitates renewal of the liquid in the jars at intervals of from two to three weeks.

(i) *Composition and Preparation of Baits*

The bait which is prepared with greater ease than, and which has proved itself to be at least as efficient as any other previously employed, is composed of 1 lb. powdered (solid) malt extract, 4 pints beer, and 1 ounce sodium fluoride. This quantity provides sufficient liquid for 32 jars (Speyer and Parr, 1942, pp. 53-56).

In preparation, the ingredients are well stirred together in a bucket, left overnight to ensure that the solids, and especially the sodium fluoride, are completely dissolved, and again stirred before measuring out in quantities of 3 fluid ounces into each jar.

The original bait recommended by Lloyd (1919, p. iv) was composed of one part thick brown treacle and two parts cheap ale, in which sodium fluoride was dissolved to give a concentration of 1 per cent.; this is roughly equivalent to 1 lb. treacle, 2 pints beer, and $\frac{1}{2}$ ounce sodium fluoride, and makes a quantity sufficient for 20 jars. In 1940 it became impossible to obtain treacle for this purpose, and the result of experiments carried out in that year (Speyer, 1940, p. 54) indicated that

cane molasses was an adequate substitute, and that it was an advantage to use one part of this to three parts ale, with the increased proportion of which the liquid dried out less rapidly in the jars without its efficiency being impaired. This bait was equivalent to 1 lb. cane molasses, 3 pints beer, and 1 ounce sodium fluoride, and sufficient for 27 jars. In these experiments and in later ones, beet molasses was found to be far less attractive to the moths when substituted for treacle or cane molasses in the baits. It now became difficult to obtain cane molasses, and during the following year, as a result of experiments in which various products of the malting industry were investigated, the substance known commercially as "powdered (solid) malt extract" was found to be a most efficient substitute, which made it possible still further to increase the proportion of ale in the mixture without adversely affecting its attractive qualities. During those trials in which the position in the glasshouses of baits containing malt-extract and cane-molasses respectively was periodically interchanged, and in which true comparison of the attractive qualities could therefore be made, 4.9 moths per jar were caught by the malt-extract, and 4.4 moths per jar by the cane molasses bait. Of the total of 83 moths trapped in 17 jars containing malt-extract bait, 25 were males and 58 were females; of the total of 61 moths trapped in 14 jars containing cane-molasses bait, 28 were males and 33 were females. In the course of these experiments (Speyer and Parr, 1941, pp. 53-56), cider was substituted for ale in some of the baits, but did not enhance their efficiency.

In other trials beer sweetened with saccharin (one part to 750 parts ale) was quite unattractive to the moths, nor did the addition of "Jargonelle Pear" (an essence employed in "sugaring" by collectors of moths), at a concentration of 0.1 per cent. add to the attractive quality of the other ingredients referred to above. During an infestation of *Cyclamen* in Germany, Zoppig (1926) caught the moths in glasses baited with apple jelly.

(ii) *Distribution of Moth-traps in Glasshouses*

From experiments carried out in a block of 12 glasshouses, each 200 ft. long by 22 ft. wide, with the number of moth-jars in each varying from 3 to 12, Lloyd (1920, pp. 97-98) computed that the effective range of each jar was less than 44 ft., and, from further records taken in isolated greenhouses, concluded that jars should be placed every 40 ft. down the houses: that is, six to each 200-ft. house, one at each end, and four others evenly distributed. He recommended that 60 jars be employed for trapping over an acre of glasshouses. As a result of observations extending over two consecutive growing seasons, Speyer and Parr (1941, p. 56) suggested that the use of 36 jars to the acre might be sufficient, and that 27 jars represented the minimum number which could be effective. From additional records obtained, it has been possible to draw out a plan, illustrated in text-fig. 6 whereby the traps may be set most economically in order to cover an acre block as represented by eight glasshouses, each 200 ft. long by 27 ft. wide.

Whereas Lloyd recommended that trapping should be continued throughout the growing season, Speyer and Parr (1941, p. 55) suggested that the practice might be dispensed with during a period extending from the beginning of June until the middle of August, and again from mid-September until the plants were cleared from the houses. On account of an annual increase in the number of moths trapped under this system in the experimental glasshouses at Cheshunt during subsequent seasons, these authors (1944, p. 38) concluded that any such curtailment of the period over which moth-jars were in use, was not justifiable in larger tomato growing districts in which the pest had long been established.

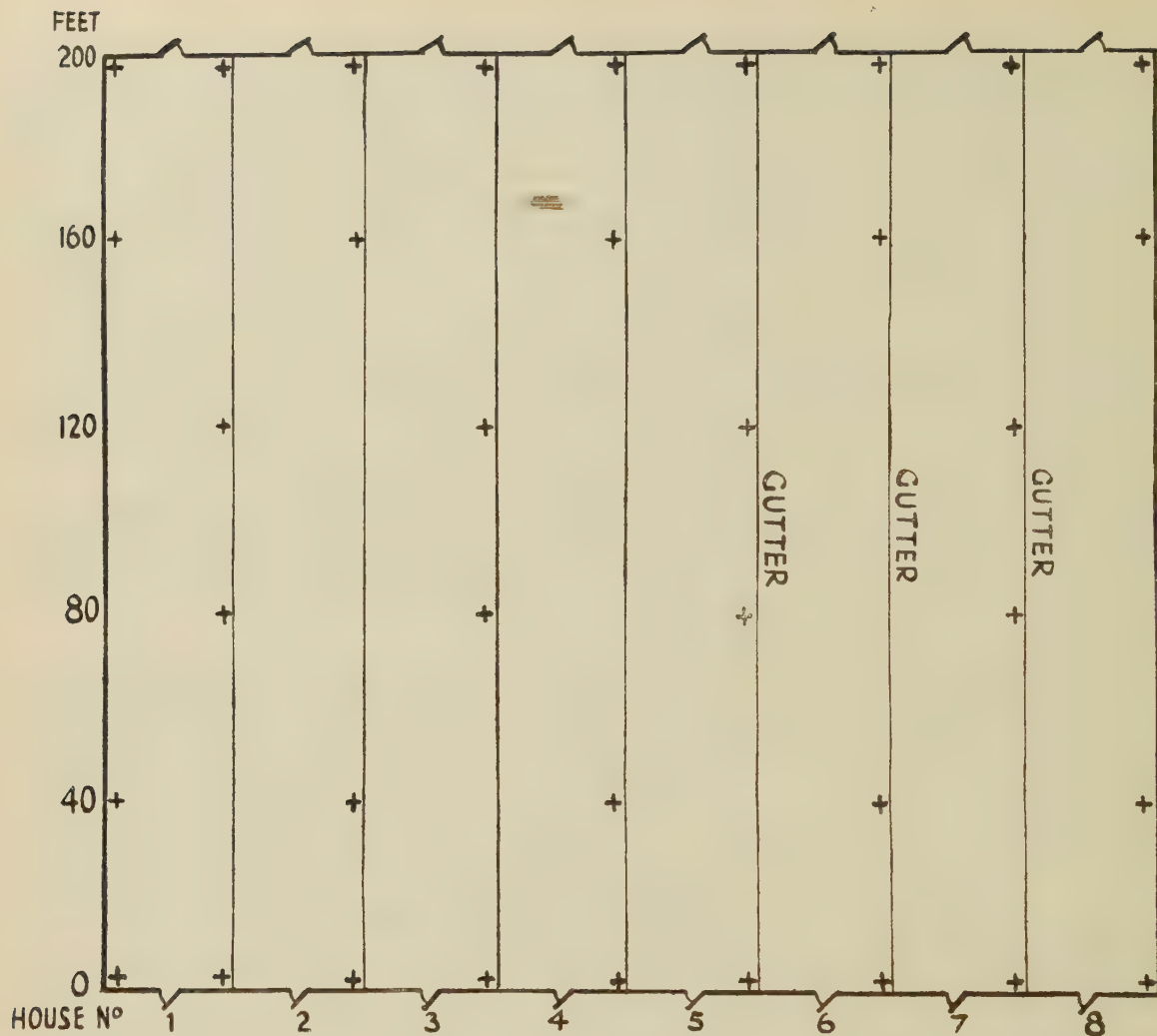
(iii) *Conditions under which Moths are attracted to Baits*

Lloyd (1920, p. 95) observed that moths which had access to poisoned baits died off much more rapidly in a warmer than in a cooler environment, probably as a result of their having imbibed the liquid more freely under the former conditions.

In experiments carried out in a warm glasshouse, he liberated 16 newly-emerged moths in a cage into which tomato plants and a jar containing a mixture of ale, treacle and sodium fluoride, had been introduced; all the moths were trapped during the first night, with the exception of one male which was found in the jar two days later.

During hot weather in July, 1941, an experiment of a similar nature was conducted in the laboratory, when 11 moths (some of which had emerged from the chrysalids several days previously) were liberated in the cage over a period of five days. During the first night after their release five males and three females were caught in the jar and one male and one female died on the floor of the cage after feeding upon the bait; the last moth, a male, died during the second night, and only three egg-masses had been deposited on the foliage of the plant.

Under these favourable conditions of temperature, the moths were attracted to the bait with little delay, and the females were trapped or poisoned before they could deposit more than a comparatively small proportion of their eggs.



Text—fig. 6

Distribution of 36 moth-traps (+) over 1 acre block of glasshouses.

Over a period of at least three months from June 20th onwards only one male moth was caught by Lloyd (1920, p. 97) in a trap hung in a glasshouse, but so fitted with a device that only moths from outside could gain access to the jar. From this experiment, he concluded that the moths are not likely to be attracted from outside to traps hung within glasshouses.

During a period of very hot weather from June 23rd to July 7th (Speyer and Parr, 1941, p. 55), when doors and ventilators were kept open throughout the night, only one moth (a female) and that upon the last night, was caught in a small glasshouse in which four traps had been set; during the first week of the experiment 19 moths were actually liberated in the glasshouse. It is probable that under such conditions the instinct of moths to escape from glasshouses overcomes their desire to feed.

(iv) *Mortality amongst Moths induced by different Poisons*

Since moths are incapable of ingesting solid substances, any poisons added to baits must be soluble in their constituents, if they are to be effective. Lloyd (1920, p. 95) observed that an attractive bait in which lead arsenate paste, at a concentration of 2 per cent., had been incorporated did not kill any of the eight moths which were given access to it over a period of six days at a mean temperature of 64° F. Excess of some poisons may adversely affect the attractive qualities of a bait, and in general it would appear that a concentration of 2 per cent. comes near to the limit. On the other hand, over-dilution of the poison may result in female moths, which escape from traps after

feeding upon the bait, having time to deposit a considerable proportion of their eggs before they eventually succumb.

From the point of view of safety in handling, and of some preservative action exerted by it upon other components of baits, none of the admittedly few poisons tested has given results materially better than sodium fluoride.

In such experiments as have been conducted, pieces of muslin soaked in the poisoned baits have been introduced into cages containing tomato plants and newly-emerged moths (Lloyd, 1920, p. 95), or pieces of rubber sponge saturated with the baits have been placed in cages containing plants, and the moths have then been liberated in them (Speyer, 1940, pp. 54-55).

Sodium fluoride

At a concentration of 1 per cent. in a bait of ale and treacle, the average life of 20 moths was 7.5 days (range four to ten days) at a mean temperature of 64° F., and 2.5 days (range one to five days) at 70° F. (Lloyd, 1920, p. 95). At the lower temperature very considerable numbers of eggs were laid after the female moths had imbibed the bait, but these were scattered all over the foliage and cage, and had not been deposited in the normal manner.

At a concentration of 2 per cent. in a bait of ale and cane molasses with an average temperature of 60° F., six moths (one male and three females eight days old, one male and one female newly emerged) were dead after the second night—one small egg-mass containing 20 eggs was laid. Of nine newly-emerged virgin females, one was dead after the second night, two after the fourth night and the remainder were alive after having been kept in the cage for from two to four days. At a concentration of 0.6 per cent. in the same bait with a mean temperature of 62° F., of six newly-emerged moths, two males died on the sixth night, and the four females which still survived after from seven to nine days, deposited nine egg-batches.

It is possible that a 2 per cent. concentration may have rendered the bait somewhat distasteful, and that the unmated females fed less freely than mated ones; a concentration of 0.6 per cent. was probably insufficient to kill moths which may not have been feeding readily during the course of the experiment.

Sodium arsenite

At a concentration of 2 per cent. in a bait of ale and treacle, the average life of five moths was three to six days (range one to five days) at a mean temperature of 70° F. (Lloyd, 1920, p. 95). In a bait of ale and cane molasses, but at an average temperature of 60° F., no deaths were recorded amongst one male and five female moths confined in the cage for from one to five days; on the fourth day the male was observed to be mating with a female, which deposited a large egg-mass upon the following night. At a concentration of 0.6 per cent. with a mean temperature of 62° F., one male died during the second night, one paired female during the fifth night, and an unpaired female was not killed in five days; two egg-masses were deposited by the paired female.

At concentrations of from 0.1 per cent. to 0.25 per cent. in a bait of ale and cane molasses and at a mean temperature of 62° F., the average life of 25 male moths was 5.2 days (range one to seven days), and of 22 females 4.2 days (range one to eight days); 13 large and eight small egg-batches (in one of which the eggs were unfertile) were deposited during the period of 15 days over which the experiments extended. The great majority of moths employed were newly emerged, and none more than three days old.

It is probable that the baits containing the two higher concentrations of the poison were rendered somewhat unpalatable to the moths, which might have fed more freely at a higher temperature. At the lower concentrations, the mortality compared favourably with that obtained with sodium fluoride, but the number of egg-masses deposited before death ensued was considerable.

Thallous sulphate

At a concentration of 2 per cent. in a bait of ale and cane molasses with a mean temperature of 61° F., only one male and one female died on the second and third nights respectively, one male survived after remaining in the cage for six days, two females for four days and one female for eight days; 10 egg-masses were deposited.

At a concentration of 0.6 per cent., three males and one female were dead after the second night.

At the higher concentration the bait was evidently distasteful to the moths, but it is possible that this poison might have proved of value at greater dilution, had opportunity arisen for further investigation.

(3) Notes on the Reaction of the Caterpillars to various Chemical Compounds and Insecticidal Products

For the destruction of caterpillars which were infesting onion, poppy and beet in Czechoslovakia, Baudys (1930) in addition to suggesting that turkeys should be kept in the plantations to eat them,* recommended that ashes be strewn over the plants. Though impracticable as applied to control of the pest in glasshouses, the latter recommendation is of some interest in the light of recent researches upon abrasion of the cuticle by gritty substances, as a result of which the internal tissues of insects lose water to an extent which may prove fatal to them.

It has been observed frequently that fumigants such as hydrogen cyanide, nicotine (see Kjellander, 1943), tetrachlorethane, and naphthalene, commonly used for the control of other pests in glasshouses, are without appreciable effect, at least when employed at dosages consistent with economic practice.

In the autumn of 1939, when caterpillars were causing injury to young cabbages at the Cheshunt Station, it was thought possible that application of salt solution might render the foliage distasteful to them. Six large caterpillars were given the choice of feeding upon an untreated pot-plant or on one to the foliage of which a 1.25 per cent. solution of common salt, with 1 per cent. potash soft-soap as a wetting agent, had been applied. In the first of two trials, the sprayed plant was entirely defoliated, and the unsprayed one hardly touched by the caterpillars during the first night; in the second, it was the foliage of the untreated plant which suffered most severely, but on the second night that of the sprayed plant was completely devoured.

Half to fully-grown caterpillars were not killed within a period of 24 hours after they had been well wetted with nicotine sulphate at a concentration of one part to 500 parts water. Kjellander (1943) found that a 1 per cent. solution of nicotine containing a wetting agent was fatal to the caterpillar; at such concentration it would neither be safe nor economic for application to tomato plants.

A proprietary brand of Pyrethrum powder, which had proved to be most effective in the control of the Rose Thrip, was applied directly to 12 caterpillars in their last instar; four of them immediately performed violent spasmodic movements, which, however, were not repeated when further applications were made; all the larvæ became lethargic, but after a few days, during which they took no food, they recovered completely. Neither Derris nor Lonchocarpus powder when applied in a similar manner, the former to older and the latter to quite young caterpillars, appeared to produce any immediate reaction, but when wetted with sprays containing these products in suspension, the caterpillars showed a tendency to drop to the ground, upon which they lay inert sometimes for very considerable periods of time.

Lloyd (1920, p. 92) found that the caterpillars were not killed within a reasonable time by suspensions of Derris powder unless they were applied at concentrations considerably above 50 lbs. of the ground root to 100 gallons water; he pointed out that both foliage and fruit of the tomato were rendered dirty by the residue left upon them, and that the growth of moulds upon this residue was undesirable.

Similar conclusions were arrived at in 1940, when proprietary products containing ground Derris root and Lonchocarpus powder were employed in experiments directed towards the destruction of caterpillars infesting cabbage and broccoli, in which it was noted that larvæ of the Green-vein White butterfly (*Pieris napi* L.) were killed by concentrations of not less than 6 lbs. to 100 gallons water, but that little effect was produced upon those of the Tomato Moth. The only really successful trial was one in which cabbage seedlings were first sprayed with 0.05 per cent. Liquid Agral and the foliage, while still wet, was thoroughly dusted with Lonchocarpus powder. The nearly full-grown caterpillars, some of which did not come into contact with the powder until the leaves had dried, began to die off on the third day, and all had been killed or were in a moribund condition by the thirteenth day; those which became ready to pupate were unable to spin their cocoons, and none of the caterpillars fed to any extent upon the sprayed foliage before they succumbed.

(i) *Derris Extracts*

Lloyd (1920, pp. 92-93) carried out extensive experiments with watery suspensions of an alcoholic extract of ground Derris root to which saponin was added as a wetting agent. It would appear that, after having extracted the root in a known volume of alcohol, he evaporated off the solvent until one-sixth part of the original volume remained.

* Incidentally, Lloyd (1920, p. 99) advocated the destruction of chrysalids in the soil of infected glasshouses by admission of fowls and pigs to them during the winter months.

Diluted to one part by weight in 1,000 parts water, this extract was applied to the foliage of tomato plants, and half-grown caterpillars liberated upon the plants all died within a period of eight days; the residue upon the leaves retained its lethal action for 20 days, and no injury to the foliage was caused, either by the spray or by feeding of the caterpillars. In further experiments, 110 caterpillars were placed upon plants to which the extract was applied at concentrations of from 10 ozs. to 5 lbs. to 100 gallons of water; similar results were obtained, except that at the lowest concentration death-rate of the caterpillars was somewhat less rapid. As a means of destroying the caterpillars after application of lead arsenate was no longer practicable, the employment of such extracts had distinct possibilities, but probably owing to the difficulty as well as the necessity of covering the leaves thoroughly with the spray at a time when the foliage in tomato houses had become dense, they do not appear to have been used upon commercial nurseries to any great extent.

Read (1938, pp. 82-83) tested the lethal properties of a Derris extract applied directly to caterpillars in all stages of their development. The extract employed contained 5 per cent. rotenone and 20 per cent. Derris resins, and was applied to the larvæ at various concentrations in sprays to which a petroleum emulsion had been added at the rate of one part in 100 parts water. Larvæ in the first and second instars were killed within a period of 48 hours by a concentration of one part extract in 2,500, and older ones, with the exception of some which were fully grown, by one of one part in 1,100 parts of the diluted petroleum emulsion. In order to kill also the fully-grown caterpillars by direct contact, it was estimated that the extract must be used at a concentration of one part in 700 parts of the diluted emulsion.

In February, 1940, a spray containing an amount of a similar extract, equivalent to 5 pints in 100 gallons of water to which 1 gallon petroleum emulsion had been added, was applied very thoroughly to 18 young tomato pot plants upon which 32 caterpillars in the second and third instar were living. By the second day after application 16 larvæ had died, and on the fourth day only three survived; these latter appeared quite healthy and had been feeding to a considerable extent upon the foliage. Of 22 caterpillars of similar age living upon nine plants sprayed lightly with an amount of colloidal lead arsenate equivalent to $2\frac{1}{2}$ lbs. to 100 gallons water, 13 larvæ had died by the second day after application, and on the fourth day none could be found upon the plants. When applied to the foliage it therefore appeared that Derris extract used in combination with petroleum emulsion did not prove to be more effective in destroying the young caterpillars than a spray containing lead arsenate.

(ii) *Cuprous Cyanide*

In June, 1934, experiments were carried out with a view to determining if cuprous cyanide could be used as a substitute for lead arsenate in sprays for destroying the caterpillars on tomato plants. This compound is insoluble in water, and at the time was stated by the manufacturers to be non-poisonous to man. It was soon discovered that the product was liable to decompose with the liberation of hydrogen cyanide, on exposure to moist air, and that under no circumstances could it be employed for application to plants in glasshouses.

The first sample with which experiments were conducted was in the form of a coarse powder, which would remain in suspension in water containing saponin long enough to make application possible. Applied at the rate of 2 to 3 lbs. to 100 gallons water, by means of a coarse-nozzle syringe to tomato plants upon the foliage of which caterpillars were placed after the spray had dried, only one out of 11 nearly full-grown larvæ survived after seven days, and four young larvæ had died or become moribund before the sixth day. During this period, the caterpillars devoured a considerable amount of the foliage.

Seven nearly full-grown caterpillars, to which foliage cut from plants sprayed with cuprous cyanide at the rate of 3 lbs. to 100 gallons water was supplied, died off over a period of eight days. With a spray containing 6 lbs. to 100 gallons water, larvæ fed less upon the sprayed leaves, the period of survival being rather longer and similar to that obtained in a check, in which lead arsenate was employed at the same concentration. There was some indication that excessive deposit rendered the foliage distasteful to the caterpillars. In no instance was the foliage injured by the compound. In August of that year, a more finely divided sample of cuprous cyanide was obtained. Well-grown tomato pot-plants to which this was applied at the rate of 3 lbs. to 100 gallons water containing 2 ozs. saponin, and upon the foliage of which eight nearly full-grown caterpillars were placed, were not injured by the spray, and all the larvæ except two, which were in a moribund state, had succumbed by the seventh day.

Eight days after 37 caterpillars in different stages of development had been placed upon 20 tomato plants to which the same spray had been applied, only four survived; considerable portions of the leaves and stems of the plants had been devoured.

In caterpillars which had taken a lethal dose of the poison, it was observed that the lower portion of the rectum tended to become evaginated.

(ii) *Fluorides and Silicofluorides*

Like lead arsenate, the fluorides and silicofluorides, notably those of sodium and aluminium, poison caterpillars which have consumed residues left upon foliage after application as sprays or powders, in quantity sufficient to constitute a lethal dose.

These compounds are less poisonous to man than arsenicals, but are sufficiently so to obviate the desirability of their application to green vegetables or to plants carrying edible fruit, unless any residue has been carefully removed by washing or wiping prior to their use as food.

Sodium fluoride applied to young cabbage plants in October, 1939, at a concentration of 2 per cent., with agram as a wetting agent, killed a high proportion of both large and small Tomato Moth caterpillars living upon them within a period of two days, but none died within this time when concentrations below 1 per cent. were employed; the sprays were injurious to the foliage. Young larvæ died within two days upon tomato plants to the foliage of which sodium silicofluoride had been applied as an undiluted powder in September, 1928; they succumbed within three days when the powder was diluted with four times its weight of Fuller's Earth, kaolin, or flour, and some died within this period when the degree of dilution was increased to one part in 100 parts of these fillers. Both younger and older larvæ sprayed directly with a saturated solution (about 0.5 per cent.), containing 0.02 per cent. saponin, died within a period of 48 hours, but when placed upon sprayed tomato plants after the foliage had been allowed to dry, the majority survived for several days. This compound may therefore act as a contact as well as a stomach poison. The foliage of tomato plants was injured to a greater or less extent, according to the degree of dilution, by all the dusts and sprays employed in the experiments. Only a small proportion of the caterpillars died within a period of four days when placed upon foliage to which powdered barium silicofluoride had been applied as a dust at a dilution of one part to four parts of flour or as a spray in saturated solution (about 0.04 per cent.) containing 0.02 per cent. saponin; neither dust nor spray caused injury to the tomato plants. Both large and small larvæ, however, died within eight days on plants to which a proprietary spray containing this compound, probably in a more soluble state, had been applied: this spray caused injury to the foliage.

Of some other metallic fluorides tested in 1939, aluminium silicofluoride was probably the most poisonous to the caterpillars, and appeared also to cause no injury to the foliage of tomato plants, but owing to its comparatively high cost, it was not employed in later investigations.

Cryolite, a double fluoride of sodium and aluminium, not soluble to an appreciable extent in water, occurs as a natural mineral or is manufactured as a synthetic product.

A sample of the natural rock, ground to pass a 250 mesh sieve, was dusted over the foliage of young tomato pot-plants in March, 1929; larvæ of different ages liberated upon the plants more than a week later all died within a period of nine days. Similar results were obtained with a suspension applied as a spray containing the equivalent of 6 lbs. powder to 100 gallons water, in which saponin had been dissolved; 30 days after the application, newly-hatched larvæ succumbed soon after they had begun to devour the leaflet, low down upon one of the plants, upon which a moth had deposited a large egg-mass. Young caterpillars upon plants, grown in the ground, to which this suspension was applied at the rate of 3 lbs. to 100 gallons water did not survive beyond the eighth day.

In March, 1931, four fully-grown and four half-grown caterpillars sleeved with muslin on the leaves of plants dusted with another sample of the ground rock all died within a period of four days. In none of these trials was any injury caused to the foliage by the mineral. When eight larvæ of different sizes were liberated upon plants sprayed with rock-cryolite suspension, and another eight of corresponding dimensions upon plants sprayed with lead arsenate at a similar concentration, those upon the latter plants were all dead by the fourth day, while upon the former one caterpillar was still alive upon the sixth day. In larger-scale experiments, it was observed that the caterpillars died off rather more rapidly with sprays containing lead arsenate than with those containing cryolite.

Experiments carried out in May, 1933, and again in June, 1934, showed that synthetic cryolite in finely-ground or in colloidal form also rendered foliage poisonous to caterpillars which fed upon it, but these products appeared to be less certain in their action, at least upon the older larvæ, than the natural mineral. When colloidal cryolite was applied to tomato plants at a concentration equivalent to 6 lbs. to 100 gallons water, three large larvæ liberated on them were all dead by the fifth day, but when foliage cut from the plants, after the spray had dried, was fed to three similar larvæ, not one of them showed any sign of poisoning after a period of six days. When plants to which suspensions of synthetic cryolite on the one hand, and the natural mineral or lead arsenate on the

other were lightly damped over after the residues had been allowed to dry, a far larger proportion of caterpillars survived after a period of one week upon the former than the latter plants.

It was therefore concluded that residues of synthetic cryolite did not adhere to the foliage and could easily be removed by shaking or damping over.

To secure better adhesion, rape oil was added to the powdered product, and a stock paste was made by stirring 4 fl. ozs. water into $\frac{1}{2}$ lb. finely ground synthetic cryolite, and then adding gradually 2 fl. ozs. rape oil.*

In small-scale experiments in which 1 to 2 ozs. of this paste was diluted with 1 gallon water, and applied to the foliage of tomato plants, the average life of 65 young larvæ liberated upon the plants was just over two days (range one to five days) and that of 18 nearly full-grown caterpillars rather less than five days (range one to nine days); three large caterpillars provided with foliage cut from the plants after the residue had dried were all dead by the sixth day.

Applied upon a larger scale to infested plants of considerable size growing in the ground, the results were quite satisfactory, but never quite so good as those obtained with lead arsenate. No injury was caused by the spray to the plants, which produced a normal crop of fruit.

Kjellander (1943) obtained fairly good results with a dust containing cryolite during an outbreak of the pest on tomato plants in Swedish glasshouses, but pointed out the necessity of wiping the fruit in order to remove any residue left upon it.

The time taken for caterpillars to die after taking a fatal dose of cryolite may vary considerably. One nearly full-grown larva which was observed in the evening to consume about half an average size tomato leaflet with a visible deposit of rock cryolite upon it was quite dead upon the following morning; another caterpillar which had begun to show signs of sickness was removed from a sprayed plant to fresh foliage and succumbed four days later. Of three similar larvæ which were in a moribund condition after feeding upon foliage sprayed with synthetic cryolite, two recovered completely when supplied with unsprayed leaves; after replacement two days later upon the sprayed plant, both succumbed within four days.

The excrement, normally voided in the form of consistent pellets, tends, in caterpillars poisoned by either cryolite, sodium silicofluoride, or aluminium silicofluoride, to become liquid; its sticky nature causes especially the older larvæ to become suspended vertically from leaflets, from which they may be observed hanging in a moribund condition. Sometimes the dorsal region of the thoracic segments assumes a dark colour (Plate V, Fig. 18).

Natural Enemies

Very few predators and parasites of the caterpillars and chrysalids have been observed in glasshouses. In November, 1927, large numbers of chrysalids in the soil of tomato houses upon a commercial nursery in Hertfordshire were destroyed by mice; the stomach of a trapped mouse was filled with fragments of the pupal integument.

Pimpla instigator F. (Plate VI, Fig. 19)

This large reddish-brown Ichneumonid is usually common in and around glasshouses in which the pest is well established. The insect is a parasite of the chrysalis and appears to be unable to deposit its eggs in chrysalids which are not enclosed in the cocoon or covered by soil or other material. The full-grown larvæ are generally to be found within the chrysalids in late autumn.

From 208 chrysalids collected at Cheshunt in September, 1933, 14 male and 46 female parasites and 80 moths emerged between September 24th and October 19th, the remainder overwintered, and from these four male and three female parasites emerged between March 20th and April 25th, and 61 moths between February 20th and May 4th giving a percentage parasitism of 32.

From 242 chrysalids, reared from caterpillars in October, 1933, covered with sawdust and placed in a cage with 14 male and 46 female parasites, 80 parasites and 112 moths emerged from February to the middle of May, 1934; upon dissection eight more chrysalids were found to contain parasite larvæ, and one moth had not emerged, giving a percentage parasitism of 44. The remaining chrysalids were either decayed, dessicated or deformed.

The seasonal emergence of the parasite does not appear to be well co-ordinated with that of its host under glasshouse conditions, for large numbers of lately emerged parasites have been observed in commercial tomato houses at times when few chrysalids of the moth could have been available.

* There remains some doubt as to whether the proportions of the ingredients given in this formula are applicable to all forms of synthetic cryolite.

Out of doors the extensive range of other lepidopterous hosts subject to parasitism by this insect precludes the likelihood of its being of any great value in reducing the population of the Tomato Moth.

Comedo opaculus Thoms. (Plate VI, Fig. 20)

In July, 1933, this small Eulophid parasite made its appearance in the tomato houses at the Cheshunt Station. The insect was reared and its pupæ survived the winter, but after completing one generation in the following spring, it vanished and was not again observed until exactly 10 years after its original appearance.

For various reasons, this parasite which is entirely an external one upon full-grown caterpillars, exerted no appreciable measure of control over its host; the chief of these was due to the habit of one or more parasites depositing all their eggs upon one and the same caterpillar. A few caterpillars with larvæ upon them were again obtained in the autumn of 1944.

Mr. W. E. China found pupæ of this parasite surrounding a dead caterpillar, possibly of *Phlogophora meticulosa* L., at East Molesey, Surrey, on December 22nd, 1932. The caterpillar was situated upon the wall of a room and had evidently been brought in upon flowers of chrysanthemum. The pupæ emerged between March 10th and 30th, 1933.

[Chevalier (1930) records *Comedo* (*Cratotrechus*) *larvarum* L. as a parasite of the caterpillar in France. According to the author's published notes this would appear to be an internal parasite during the early instars. Silvestri (1923) describes the species as an external parasite of *Tortrix viridana* L. and states that normally it is a parasite of *Cheimatobia brumata* L.]

Apart from the two parasites referred to, a record of only one other from glasshouses is to hand. A chrysalis collected by Mr. O. Bevan Lean in a tomato house at Newbury, Berks, on October 14th, 1936, contained a number of Hymenopterous larvæ, but owing to breakage the parasites died before they were able to pupate, and a determination could not be obtained.

Zorin and Zorina (1929) give an account of parasites observed out of doors at Leningrad, comprising:—

Parasites of the egg: *Hymenoptera* (Trichogrammidæ) *Trichogramma evanescens* Westw.

Parasites of the caterpillar: *Hymenoptera* (Braconidæ) *Apanteles affinis* Nees, *Microgaster marginatus* Nees (egg deposited in caterpillar shortly before hatching); (Eulophidæ) *Eulophus pectinicornis**, (Ichneumonidæ) *Anilastus coxalis* Brischke, *Anomalon cerinops* Grav.,* *Banchus obscurus* Meyer* (1926) and *volutatorius* L., *Exetastes cintipes* Retz., (*H*)*enicospilus ramidulus* L.,* *Ophion luteus* L., *Sagaritis erythropus* Thoms. *Diptera* (Tachinidæ) *Ernestia consobrina* Mg.,* *Lydella nigripes* Fall.* (The Ichneumonid, *Barichneumon fabricator* F. and the Tachinid, *Voria trepida* Mg. were bred only once from the caterpillar.)

The authors give biological notes on many of these parasites, with illustrations of those marked with an asterisk; they also record the fungus *Oospora destructor* upon the caterpillar and *Bacillus alvei* upon the chrysalis. Zorin (1927, 1930 and 1936) describes a method of rearing the egg parasite *Trichogramma evanescens* Westw., the life history of *Microgaster marginatus* Nees, and that of *Eulophus pectinicornis* L. The last-named is a parasite of the same type as *Comedo opaculus* Thoms. Menozzi (1938) records in Italy a Chalcid, *Brachymeria intermedia* Nees, and the Tachinids, *Neopales pavida* Mg. and *Voria ruralis* Fall as parasites of the caterpillar. Rodendorf (1935) observed that the Tachinid, *Tachina civilis* Rond., laid eggs under laboratory conditions upon the caterpillars in Russia.

Lloyd (1920, p. 87) cites the carnivorous beetle *Carabus granulatus* L. as a predator. He also refers (loc. cit., p. 72) to the peculiar disease known as "flacherie," which at that time was prevalent amongst caterpillars in infested glasshouses and was possibly associated with overcrowding. A larva infected with the malady becomes soft and light-coloured, ceases to feed, and soon after turns black. The disease has now become rare, and amongst many hundreds of larvæ bred more recently only one (in August, 1933) was observed to become infected (Plate VI, Fig. 21).

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EXPLANATION OF PLATES

Plate

I. STAGES IN THE LIFE-HISTORY

- Fig. 1. Egg-mass. X8. (a) Four days, (b) eight days, after deposition.
 „ 2. Larvæ four days old, at the 1st ecdysis. X4.

II. STAGES IN THE LIFE-HISTORY

- Fig. 3. Larva in 4th instar. X3. (a) from above; (b) from the side.
 „ 4. Larva (brown form) in 6th instar. X2.
 „ 5. Full-grown caterpillar (green form). Nat. size.
 „ 6. Chrysalis, extracted from cocoon. X2.
 „ 7. Male (above) and female moth. X2.
 „ 8. Moths showing range in size. Nat. size.

III. INJURY CAUSED TO THE TOMATO PLANT

- Fig. 9. Leaflet skeletonized by young caterpillars.
 „ 10. Fruit excavated by caterpillar.
 „ 11. Caterpillar feeding in pith of broken stem.

IV. INJURY CAUSED TO CARNATION

- Fig. 12. Flowerbuds damaged by older caterpillars.
 „ 13. Petals eaten by older caterpillars.
 „ 14. Cavity in leaf made by newly-hatched caterpillar.
 „ 15. Holes eaten in leaf by young caterpillar.

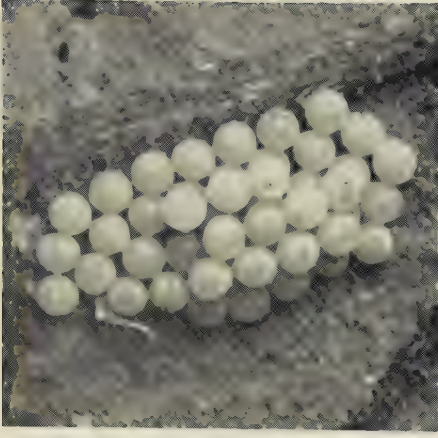
V. TRAPPING AND POISONING OF CATERPILLARS

- Fig. 16. Caterpillars trapped on sack in tomato house.
 „ 17. Caterpillar poisoned by lead arsenate.
 „ 18. Caterpillar poisoned by cryolite.

VI. NATURAL ENEMIES

- Fig. 19. *Pimpla instigator* F. Parasite of the chrysalis. Nat. size. (a) Full-grown larva extracted from chrysalis. (b) Adult emerging from chrysalis. (c) Male parasite. (d) Female parasite.
 „ 20. *Comedo opaculus* Thom. Parasite of the caterpillar. (a) Male parasite X10 (b) Larvæ feeding on caterpillar X3. (c) Female parasite X10.
 „ 21. Caterpillar infected with “flacherie” disease.

NOTE.—Fig. 9, photo by J. E. Morton. Fig. 10 from photo by Ll. Lloyd. Figs. 11 and 16, photos by Ll. Lloyd (1920) by kind permission of the Association of Applied Biologists.



(a)



(b)

FIG. 1

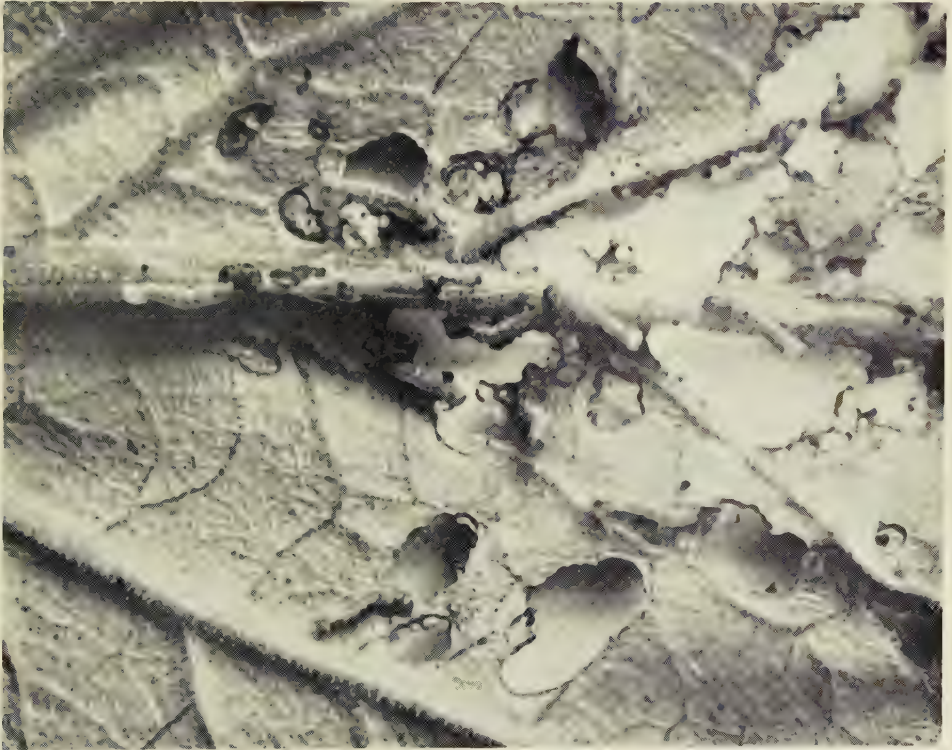
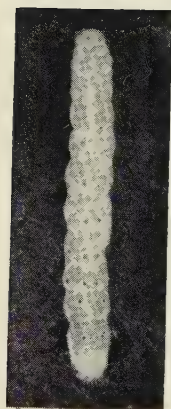
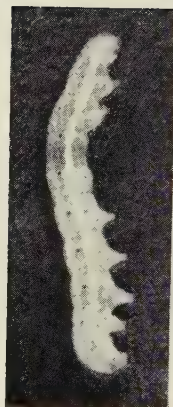


FIG. 2

Stages in the life history. Eggs and young caterpillars.



(a)



(b)

FIG. 3

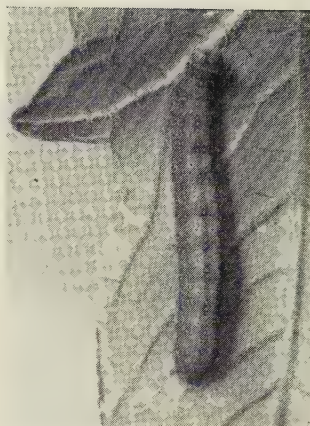


FIG. 4



FIG. 5



FIG. 6



FIG. 7



FIG. 8

Stages in the life history. Caterpillar, chrysalis, and moth.



FIG. 9



FIG. 10



FIG. 11

Injury caused to the Tomato plant.



FIG. 12

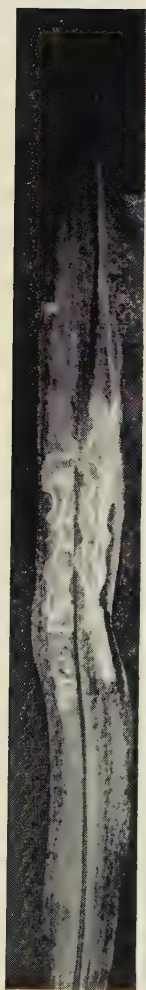


FIG. 14



FIG. 13

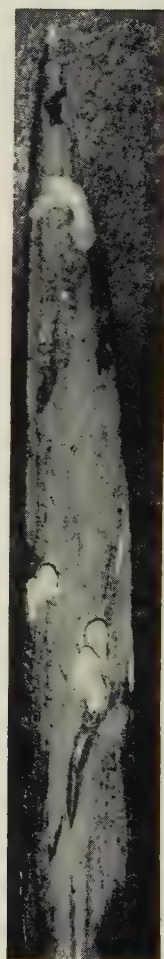


FIG. 15

Injury caused to Carnation.



FIG. 16



FIG. 17



FIG. 18

Trapping and poisoning of caterpillars.



(a)



(b)



(c)



(d)

FIG. 19



(b)



(a)

FIG. 20



(c)

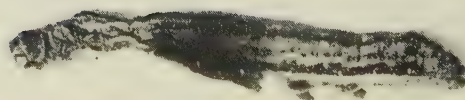


FIG. 21

Natural Enemies.

2. INSECTICIDES

By W. H. READ

(1) General

(a) Acaricides

Work has continued on the use of azobenzene for the control of the red spider mite (*Tetranychus telarius* L.) on glasshouse crops.

In addition to experiments in which the azobenzene fumigations were conducted by spraying acetone solutions of azobenzene into the free air-space of glasshouses as described by Read (1), trials were made also in which azobenzene was volatilised from pyrotechnic compositions. These latter will be referred to as smoke generators and the product of their ignition as an azobenzene smoke. Experiments were also made in which azobenzene was distributed in glasshouses with a mechanical fog generator. In one test with this generator a solution of azobenzene in a refined petroleum oil was employed and in the other a suspension of azobenzene. Although the control of the pest obtained in these preliminary trials was promising, severe damage was caused to plants near the place of injection of the azobenzene fog. It has been suggested that modification of the process so that injection was not continuous might overcome this trouble.

Delays in obtaining apparatus have hindered laboratory determinations of the acaricidal values of compounds related to azobenzene when employed as fumigants by atomising their solutions in highly volatile solvents.

The emissive efficiencies of a number of experimental azobenzene smoke generators have been examined in the laboratory by chemical determination of the percentage of azobenzene originally present which is discharged in the smoke.

The degree of control of the red spider mite obtained by atomising a solution of azobenzene in acetone in isolated glasshouses and blocks of houses has been compared with that obtained under commercial conditions by spraying with a proprietary petroleum emulsion. A more detailed description of these trials is given later.

The examination of the acaricidal values of a number of organic phosphorus compounds has been commenced. Solutions of hexaethyl tetraphosphate (H.E.T.P.) are highly toxic to the active stages of the red spider mite though of low ovicidal value. Atomised solutions of H.E.T.P. in acetone have also given excellent control of adult mites in preliminary trials in a chamber of 750 cu. ft. capacity and the use of H.E.T.P. in conjunction with azobenzene is being investigated since the latter is not rapidly effective against adult mites.

(b) Aphicides

Sprays containing 0.05 per cent. hexaethyl tetraphosphate (H.E.T.P.) have proved very effective for controlling the aphid (*Myzus persicae* Bulz) on carnations and do not appear to cause the slight bleaching of the tips of the leaves which frequently follows the application of nicotine sprays. Very variable results have been obtained in glasshouse trials by atomising solutions of H.E.T.P. in acetone for the control of aphids, and the promising results obtained in preliminary trials in a glasshouse of 750 cu. ft. capacity were not confirmed by trials in a carnation house of 40,000 cu. ft. capacity.

(c) Nematocides

A preliminary trial was made with D.D. (a proprietary product containing 1 : 3-dichloropropene and 1 : 2-dichloropropane) on a commercial nursery for the control of the potato eelworm *Heterodera rostochiensis* Woll. in tomato soils. Dosages at the rate of 400 lbs. per acre and 600 lbs. per acre were carried out in replicated plots, the injections being made at intervals of 15 ins. and at a depth of 8 ins. Although the plants in all the plots treated with D.D. showed a response to the treatment by increased vigour during the early part of the season, cyst counts made 25 weeks after treatment showed that there was no significant difference in the numbers of viable cysts in the treated and untreated plots. Later in the season there was no apparent difference between the plants in the treated and untreated portions of the glasshouse. The cause of the remarkable initial increase in plant growth in response to treatment of the soil with D.D. is worthy of investigation, particularly as the soil throughout the house was treated with formaldehyde prior to applying D.D. Any partial sterilizing effect asserted by the D.D. was therefore additional to that given by the formaldehyde. It should be stated that the growth of plants throughout the house was poor owing to soil conditions which could best be remedied by steam sterilization of the soil. Treatment with D.D. appears to be of much less value in treating tomato soils for the control of *H. rostochiensis* than for the control of the root-knot eelworm *H. marioni* (Cornu).

(2) The Practical Control of the Red Spider Mite (*Tetranychus telarius* L.) with Azobenzene

A Comparison with Petroleum Emulsion Sprays

Trials have been made in single glasshouses and in blocks of inter-connecting houses to compare the control of the red spider mite (*Tetranychus telarius* L.) obtained by fumigating with azobenzene with the control obtained by spraying with a glasshouse type of petroleum emulsion. Owing to the difference in the nature of the two processes replicated treatments under the same conditions of culture, etc., were impossible. The results have been assessed, therefore, by determining the percentage kills obtained.

Experimental.—The azobenzene employed in these trials was a recrystallised product having a setting point of 62° C. The houses were fumigated by atomising with a paint spray gun a quantity of a 30 per cent. solution of azobenzene in acetone equivalent to 8 grams azobenzene per 1,000 cu. ft. glasshouse capacity. The spray gun (de Vilbis, type CH) was fitted with a graduated glass container and was operated by compressed air at a pressure of 45 lbs. per sq. in. When fumigating the houses by this method the operator walked slowly backwards down the paths of the houses directing the spray from the gun into the air in such a manner that it did not come into direct contact with the plants. The graduated container enabled the solution to be discharged at a moderately uniform rate after slight practice. The rate of discharge employed in these trials was 3 ozs. of azobenzene solution per minute. Higher rates of discharge can be employed when the plants are small and there is ample free air-space above them, or later in the season when the fruit has been picked from the lower trusses so that the spray can be discharged below the level of the foliage and fruit. Solutions of azobenzene in volatile solvents are very injurious to plants on direct contact and there is difficulty in preventing entirely damage due to contact between droplets of the solution and plants on either side of the path when the spray cannot be discharged well above the plants or below the level of the foliage.

The glasshouses remained closed for a period of four hours after treatment with azobenzene except where the excessively hot weather made it necessary to commence the fumigation in the evening, in which case the houses remained closed overnight.

The petroleum emulsion was a proprietary product approved for use on glasshouse crops by the Ministry of Agriculture and was one of the most effective of a number of proprietary emulsions examined by Speyer (2). The concentration of petroleum in the spray fluid was 0.7 per cent. and the spraying in these trials was accomplished with possibly more care than is usual in commercial practice.

A number of factors presented some difficulty in deciding the best method of assessing the results. Since one treatment was a fumigation process, different houses had to be employed for the two methods of control and replicated pairs of treatments under the same cultural conditions were impossible. The severity of attack by red spider mite varies very considerably not only from house to house but also from plant to plant within a small area and no satisfactory method of measuring the rate of increase or decrease of the mite population as a result of any treatment has been devised. The impossibility of replicated treatments in one house renders plant yields valueless in comparing the results. Assessment had therefore to be made on the basis of percentage kills of the mites and owing to the strain of counting mites and eggs, no differentiation was made between the stages of the mites other than between eggs and stages other than eggs. The problem is further complicated by the reaction of the mites to the azobenzene since many of the mites fall from the plants when fumigated, and by the time taken by mites to succumb to the action of azobenzene. In view of these considerations the procedure adopted was as follows. Mite infested tomato shoots or leaves with the ends of their stems immersed in water contained in small flasks were stood on sheets of paper in different positions and at different heights in the glasshouses fumigated with azobenzene. At the end of the period of fumigation the mites on the papers were placed on tomato leaflets in petri dishes and counted. Five days after treatment the numbers of these mites which showed no movement or only made feeble, unco-ordinated movements when touched were classified as dead. The numbers of dead and live mites other than eggs remaining on the shoots were also recorded five days after treatment.

The procedure where the results of spraying with the petroleum emulsion were recorded was to take leaves or shoots from plants at various positions in the houses five days after spraying and count the numbers of live and dead mites.

To determine the effect on the eggs of both azobenzene fumigation and spraying with petroleum emulsions leaves or small sideshoots were taken at random from plants at different positions in the houses and all stages of the mite other than eggs removed. These leaves or shoots

were kept in flasks of water in a glasshouse, the average temperature of which exceeded 70° F., and the numbers of hatched and unhatched eggs recorded after 10 days.

Results

The results of the trials are tabulated together with the total numbers of mites or eggs counted in each trial and the number of samples taken from the treated houses.

TABLE I
DEATH OF MITES AND EGGS ON TOMATOES FOLLOWING AZOBENZENE FUMIGATION
AND PETROLEUM EMULSION SPRAYS

	Eggs				Stages other than Eggs			
	Total	No. of Samples	Mean % Kill	S.E.	Total	No. of Samples	Mean % Kill	S.E.
Azobenzene 1 (8g/1,000 cu. ft.). Temp. 70°-73° F. Glasshouse capacity, 52,400 cu. ft. ...	1594	17	98.5	±0.8	844	8	85.6	± 4.17
Azobenzene 2 (8g/1,000 cu. ft.). Temp. 78°-70° F. Glasshouse capacity, 22,400 cu. ft. ...								
Azobenzene 3 (8g/1,000 cu. ft.). Temp. 83°-69° F. Glasshouse (cucumber type), 6,000 cu. ft.	858	8	97.1	±1.06	605	4	88.6	±11.25
Foliage dense ...	648	8	95.7	±4.3	856	8	86.9	±2.08
Petroleum emulsion spray 1 (0.7% petroleum). Tomatoes 6 ft. high, well trimmed ...	423	10	78.0	±8.9	103	10	76.4	± 8.07
Petroleum emulsion spray 2 (0.7% petroleum). Area of house, 250 sq. ft. and spraying efficiently accomplished ...	722	12	91.9	±3.0	736	12	68.1	± 4.9
Petroleum emulsion spray 3 (0.7% petroleum), cucumber type glasshouse. Foliage dense ...	591	17	89.7	±5.0	478	13	56.7	± 7.7

It appears from the results of these trials that the control of the eggs of the mites obtained by atomising solutions of azobenzene is superior to that obtained by spraying with a petroleum emulsion selected from a number of petroleum emulsions, approved by the Ministry of Agriculture for use on glasshouse crops, on account of its high performance in a previous trial by Speyer.² The deviations in response to spraying with this emulsion indicated by the standard errors are probably due to failure to obtain uniform application of the spray fluid and not to heterogeneity of the mite population since by carefully spraying small plants Speyer² obtained 70 per cent. kill of active stages, 100 per cent. kill of resting stages and 100 per cent. kill of eggs. The poor control obtained in the third spraying test is attributable to the difficulty of applying the spray efficiently due to the dense foliage of the plants. The third trial with azobenzene was conducted with plants of similar foliage density.

The mean percentage kill of stages other than eggs was also higher where azobenzene was used but it must be admitted that the method of assessing results is open to criticism. The percentage kills of mites which were collected from the papers on which the shoots or leaves were stood were Trial 1, 99.0 per cent.; Trial 2, 100 per cent.; Trial 3, 98.5 per cent.; showing that almost complete kill of fallen mites was obtained. This can probably be attributed to the settling of particles of azobenzene on these mites. There is evidence¹ that under certain conditions some of these mites may survive. No evidence of deposition of particles of azobenzene on the underside of surfaces has been obtained.

Another factor is the time taken for mites, particularly adult mites, to die as a result of treatment with azobenzene in which period viable eggs may be laid by adult females. Petroleum emulsions, on the other hand, are more rapid in their effect. A period of five days between treatment and counting the dead and living mites was considered most suitable for the purpose of these trials, although somewhat higher figures would have been obtained as the results of the azobenzene trials, had a longer period elapsed between treatment and counting.

Furthermore, no account is taken of those mites which may be washed from the leaves by the forcible application of petroleum emulsion sprays when assessing the results of the spraying trials.

Attempts are being made to devise an alternative method for assessing results which will remove the disadvantages mentioned and allow of fuller statistical treatment of the data obtained.

Acknowledgments are due to Mr. Parr for help in recording the results.

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¹ Rep. Exp. Res. Sta., Cheshunt (1946), 32, 59.

² Rep. Exp. Res. Sta., Cheshunt (1943), 29, 54.

IV. CHEMICAL INVESTIGATIONS

I. NITRIFICATION STUDIES

by O. OWEN and G. W. WINSOR

WORK on the availability of nitrogen in organic fertilisers, commenced last year, has been continued. The technique is essentially similar to that given in the 1946 Report (p. 66), nitrates being determined by the phenol-disulphonic acid method.

It is clear that a fundamental basis for comparison of the different fertilisers lies in a study of the *kinetics* of their transformation by micro-organisms in the soil. For this purpose conditions of controlled temperature are almost essential. Apart from the need to reduce temperature variations throughout the period of reaction, control of the actual temperatures was desirable in view of the considerations given at the end of the 1946 Report (p. 70). The necessary thermostatic equipment did not, however, become available until late in the year, and consequently the kinetic aspect of the work has largely been omitted from the present Report. Despite these limitations of the earlier work, the results obtained show a number of interesting features, and furthermore, serve to confirm those of the 1946 Report in many ways.

It so happened that in the early months of the year laboratory temperatures were unusually low so that it was possible to observe the general effects of low temperatures on nitrification. The data are summarised below:—

Month	Temperature Range			Mean Temperature
January	7-16° C.			11° C.
February	7-16° C.			13° C.
March	7-17° C.			15° C.
April (first two weeks)	13-17° C.			15° C.

According to Waksman¹ ammonia formation occurs in the temperature range 15-60° C., and nitrification between 15 and 40° C., with an optimum at approximately 35° C. The mean temperatures at the beginning of the year were thus below the minima quoted above and in this respect conditions were unfavourable to nitrification. This is in fact shown by the first three sets of nitrification tests briefly described below.

In the first experiment an attempt was made to compare the rates of nitrification of dried blood, hoof and horn, and guano. This was intended as a confirmation of the 1946 results, but as stated above the conditions proved far less suitable for rapid nitrification. The soil used had the following composition:—

Nitrogen	0.34 per cent.
Phosphoric Acid (P ₂ O ₅) (soluble in 1 per cent. Citric Acid Solution)	0.03 "
Potash (K ₂ O) (soluble in 1 per cent. Citric Acid Solution)	0.02 "
Organic Carbon (Walkley and Black)	2.98 "
Total Carbonate, as Calcium Carbonate	0.37 "

Initial Nitrate Content:

Parts per million of Nitrate Nitrogen (p.p.m. NO₃-N) 42

Each fertiliser was added to 2 Kg. of soil containing 17.1 per cent. of water in quantities calculated to provide nitrogen corresponding to 73 parts per million in the soil. The latter value, an arbitrary choice, was somewhat less than that used in the 1946 experiments, namely, 95 p.p.m. The value of 17.1 per cent. moisture, found for the soil at the commencement of the experiment, corresponds to

TABLE I

Time in Days:	1	4	8	21	43	66	87
Fertiliser	Nitrate—Nitrogen in p.p.m.						
Guano	4	0	4	7	25	38	53
Hoof and horn	-7	-8	0	-	5	2	39
Dried Blood	0	-8	-3	0	-5	1	18

approximately 60 per cent. of the moisture equivalent as determined by the suction method of Bouyoucos, a value of the order frequently used in soil nitrification studies. The results, expressed as differences from control in parts per million of nitrate-nitrogen, in other words the nett gain in nitrate due to the fertiliser added, are given in Table I.

The data indicate but little nett gain of nitrate from guano in the first three weeks under these conditions, while apparent losses were found in soils treated with hoof and horn and dried blood during this period. A period of some six weeks elapsed before a gain of nitrate resulted from treatment with hoof and horn, and a similar delay of not more than 12 weeks was found with dried blood. The slow production of nitrates is attributed to the low prevailing temperatures already discussed; these conditions appear to have emphasised still further the differences between these three fertilisers found in 1946.

In view of the slow nitrification obtained in the preceding experiment further series of tests were made with other soils. In the first of these, referred to as Series 11, a very rich old cucumber soil was used. The analysis of this soil, reported below, is in marked contrast to that of the poor soil in Series 1, particularly with regard to nitrogen:—

N.	...	...	...	...	...	0.67 per cent.
P ₂ O ₅	...	...	...	...	...	0.32 "
K ₂ O	...	...	...	...	...	0.089 "
Organic Carbon	...	...	...	...	...	6.03 "
CaCO ₃	...	...	...	...	...	1.86 "
pH	...	...	...	...	...	6.74 "
Initial NO ₃ -N Content	...	...	...	...	...	630 p.p.m.
Initial Water Content	...	...	...	...	...	22.6 per cent.

The level of application of the three fertilisers was increased to provide nitrogen corresponding to 155 p.p.m. in the soil with the object of improving analytical accuracy. The moisture content corresponds to 63 per cent. of the moisture equivalent, a value similar to the previous soil. The results, given as actual values of nitrate-nitrogen in the soils in order to emphasise the relative changes in control and treatment, are recorded in Table II.

TABLE II

Days:			1	4	6	14	25	32	57
Fertiliser			Parts per million of Nitrate-Nitrogen						
Dried Blood	...	...	—	—	606	603	658	625	646
Hoof and horn	...	...	—	—	640	656	651	614	710
Guano	...	...	—	569	620	644	636	622	726
Control	...	...	630	640	641	660	692	683	731

It will be seen that the control soil showed a considerable increase in nitrate during the experiment while the nitrate content of the soil treated with fertilisers was in every case less than that of control throughout the period of some eight weeks. It is of interest that at the end of this period the smallest apparent loss of nitrate compared with control was due to guano, the most readily nitrified of the three fertilisers in the preceding experiment, while the greatest apparent loss was found after treatment with dried blood, the least readily nitrified in Series 1.

The data show that conditions were not suitable for nitrification in this rich old cucumber soil. This cannot be attributed to an adverse carbon/nitrogen ratio for the soil, the value of 9.02 being well within the range normally found for glasshouse soils. Apart from the low prevailing temperatures, the most likely causes are considered to be an excess of readily assimilable organic food for bacteria and the high initial level of nitrate.

Conditions for the study of nitrification still remained unsuitable. It was therefore decided to perform the third series of experiments using a soil which had actually shown ready nitrification of added fertilisers in 1946. This batch of soil contained the residues from the previous series of nitrification tests in 1946, together with a higher nitrate content. During storage the moisture content had fallen to 25.7 per cent., a value corresponding to 72 per cent. of the moisture equivalent and therefore considered quite satisfactory for purposes of nitrification. Fertilisers were added in quantities calculated to increase the nitrogen content of the soil by 88 parts per million, an arbitrary

value only slightly less than that used in the original 1946 experiments. The results are given in Table III as percentage of added nitrogen nitrified.

TABLE III

Fertiliser	Days:	4	12	20	32	55	71
	Percentage of added Nitrogen Nitrified						
Guano		14	75	72	60	77	74
Hoof and horn		-2	10	25	10	52	59
Dried Blood		9	9	5	13	33	22

The results show considerable fluctuations, probably due in part to variations in room-temperature. Compared with Series I and II, however, nitrification occurred fairly readily, although the rate was less than in 1946. As in the 1946 experiments, guano showed the most rapid nitrification, but now the apparent difference between hoof and horn and dried blood was considerably more marked. While a more complete comparison of the two series of experiments is hardly possible owing to the different conditions, the results show that the partial failure to obtain ready nitrification in Series I and II could not entirely be attributed to low temperatures, but must in part be due to the chemical or biological nature of the soils themselves. By the end of these experiments in April laboratory temperature had risen somewhat and no further difficulties arose from this cause.

The fourth series of nitrification tests was made from April to June, the temperature range being 12-27° C. The soil was a maiden loam having the following analysis:—

N.	0.73 per cent.
P ₂ O ₅	0.014 "
K ₂ O	0.012 "
Organic Carbon	6.27 "
CaCO ₃	4.64 "
Initial Nitrate Content	202 p.p.m.

From the analysis it is seen that this soil, though received as a maiden soil, is unusually rich in carbon and nitrogen. For the comparison of nitrification of dried blood, hoof and horn, and guano, quantities corresponding to 180 p.p.m. of nitrogen in the soil were added to 1.7 Kg. batches of moist soil (27.3 per cent. water). To obtain preliminary information about the response to different levels of application, two further treatments with hoof and horn were included with nitrogen added to give 90 and 360 p.p.m. respectively.

The results, expressed as differences from control in parts per million nitrate-nitrogen instead of percentages nitrified in order to illustrate the response to level of application for hoof and horn, are given in Table IV.

TABLE IV

Fertiliser	Days:	2	5	10	16	23	31	40	58
	Theoretical Max. p.p.m.	Nitrate-Nitrogen, parts per million							
Guano	180	24	76	135	132	—	—	—	—
Dried Blood	180	9	12	47	56	81	104	107	110
(i) Hoof and Horn	90	8	—	23	32	46	49	68	67
(ii) " "	180	15	22	53	57	101	116	134	137
(iii) " "	360	16	—	103	153	202	217	254	272

On examining the data for guano, hoof and horn II, and dried blood, each at the same level of application, the following conclusions appear:—

- (1) Guano was nitrified very rapidly, reaching a maximum conversion to nitrate of 75 per cent. in 10 days;
- (2) Hoof and horn gave a maximum conversion to nitrate of 76 per cent. in 40 days;
- (3) Dried blood gave a maximum conversion of 61 per cent. in 58 days.

These results support the previous data for both 1946 and 1947 in showing guano to be far more readily nitrified than either hoof and horn or dried blood. They are also in agreement with Series I and III of this report in showing this particular sample of hoof and horn to be more readily nitrified than the dried blood.

The data for hoof and horn at three levels of application show that at any one time of sampling there is a general relationship between nitrogen added and nitrate produced. On expressing the results as percentage nitrified after various intervals of time it is found that, for this fertiliser in this soil, the values are very largely independent of the levels of application used (Fig. 1).

The results of this experiment on response to level of application were entirely unexpected; a fuller investigation with a series of soils and fertilisers is being made, some of the results being given in a later section of this Report.

The Influence of Phosphate on Nitrification in a slightly Acid Soil

For the fifth and last series of experiments at laboratory temperature, preliminary trials were made concerning the effect of phosphate on the nitrification of hoof and horn. These were intended to serve as a basis for more comprehensive studies at controlled temperatures.

The soil was a maiden clay loam delivered for re-soiling on the nursery, the analysis being given below; the figures indicate an unusually low carbon/nitrogen ratio:—

N.	...	...	...	...	0.24 per cent.
P ₂ O ₅	...	...	...	...	0.022 "
K ₂ O	...	...	...	...	0.026 "
Organic Carbon	...	...	...	...	1.15 "
CaCO ₃	...	...	...	...	None
pH	...	...	...	...	5.5 "
Initial Nitrate Level	...	...	...	...	17 p.p.m. NO ₃ -N
Initial Moisture Content	...	...	...	...	20.8 per cent.

Six batches of soil weighing 1.7 Kg. were used, treated as follows:—

Pot 1	...	...	Control
" 2	...	...	2 g. Hoof and Horn
" 3	...	...	" " " +10 g. Superphosphate
" 4	...	...	" " " +30 g. "
" 5	...	...	" " " +30 g. " +4 g. Calcium Hydroxide
" 6	...	...	" " " +5 gm. Potassium Phosphate (K ₂ HPO ₄)

2 g. hoof and horn corresponds to 194 p.p.m. of nitrogen in pot 2.

The experiment was continued for 77 days, during which the control soil showed an increase of nitrate from 17 to 46 p.p.m. NO₃-N. The results, expressed as p.p.m. gain over control, are shown in Fig. 2.

The various fertiliser treatments produced marked differences in pH:—

TABLE V
pH VALUES

Time in Days	Pot 1	Pot 2	Pot 3	Pot 4	Pot 5	Pot 6
3	5.76	—	—	4.69	5.73	6.51
29	5.45	5.41	5.00	4.78	5.51	5.73
48	6.00	5.56	5.13	5.34	5.94	5.99
54	5.49	5.22	4.90	4.78	5.28	5.62
75	5.72	5.44	5.04	4.86	5.48	5.72
Mean	5.68	5.41	5.02	4.69	5.59	5.91

The results may be summarised as follows:—

- (1) Addition of superphosphate to a slightly acid soil retarded nitrification in three series of tests (3, 4, 5).
- (2) The addition of superphosphate with lime to prevent increased acidity reduced this retardation, but the rate of nitrification was still less than in pot 2 (hoof and horn only).
- (3) Apparent loss of nitrate in the early stages followed the use of superphosphate.

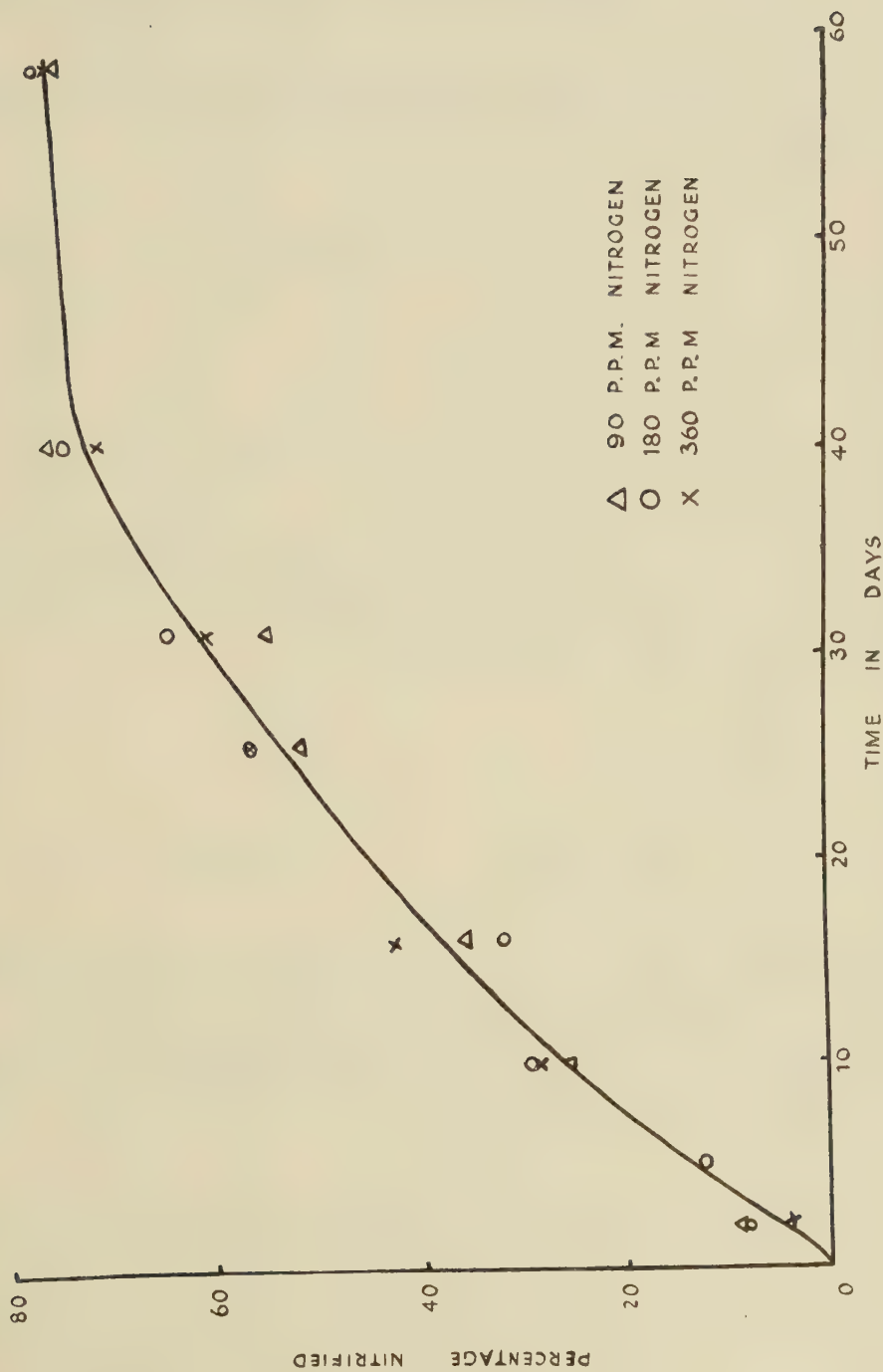


FIG. 1 The percentage of hoof and horn nitrified at different levels of application corresponding to 90, 180 and 360 parts per million of nitrogen in the soil.

- (4) Addition of potassium phosphate (K_2HPO_4), having an alkaline reaction, increased the pH of the soil, particularly at first. In this medium hoof and horn nitrified readily.
- (5) Fig 2 shows that a period of inactivity preceded nitrification.
- (6) There is some general relation between pH and nitrification. In Table VI, below, the mean pH throughout each treatment is compared with the amount of nitrate formed in an arbitrary period of 42 days.
- (7) There is no obvious relationship between the amount of phosphate in the aqueous extracts of soil and the increase in nitrate. The water-soluble phosphate data, estimated colorimetrically after 54 days, are given as parts per million of phosphoric acid (P_2O_5) in the last column of Table VI.

TABLE VI

Treatment					NO_3-N p.p.m.	pH	P_2O_5 p.p.m.
6.	Hoof and Horn	+ K_2HPO_4	...	...	130	5.9	243
2.	"	only	...	...	64	5.4	Trace
5.	"	+30 g. superphosphate	+ $Ca(OH)_2$	...	53½	5.6	233
3.	"	+10 g. superphosphate	...	...	32½	5.0	35
4.	"	+30 g.	"	...	—9	4.7	210

Nitrification at Constant Temperature

The components for a large constant temperature chamber finally being obtained, an experiment to confirm previous nitrification work was planned under conditions of controlled temperature. The materials tested were four commercial organic fertilisers, together with three pure nitrogenous compounds for comparison. To follow up the experiment already described with hoof and horn at different concentrations, each substance was tested at three different levels of application. The soil analysis is given below together with experimental details.

N.	...	...	...	...	0.67 per cent.
P_2O_5	...	...	...	...	0.011 "
K_2O	...	...	...	...	0.020 "
Organic Carbon	...	...	...	...	4.62 "
$CaCO_3$	...	...	...	...	5.16 "
Original pH	...	...	...	...	7.43 "
" Nitrate Content	...	...	...	...	151 p.p.m. NO_3-N
" Water Content	...	...	...	...	24.7 per cent.

Twenty-four pots, each containing 1.5 Kg. moist soil, were grouped in batches of eight, each batch including seven fertiliser treatments and a control. Series A received total nitrogen to give 90 p.p.m. calculated on the oven-dry soil, series B 180 p.p.m. and series C 360 p.p.m. To facilitate comparison of results after equal intervals of time, series B and C were started one and two days respectively after A. The thermostat was maintained at 23° C. The results expressed as parts per million nitrate-nitrogen (NO_3-N) gain over control, are given separately for the three series in Tables VII, VIII, IX. The maximum amount of nitrate-nitrogen formed in each case is also recorded as a percentage of the total nitrogen added.

TABLE VII
SERIES A. 90 P.P.M. NITROGEN

Fertiliser	4 Days	7 Days	12 Days	18 Days	25 Days	33 Days	46 Days	Max. %
Dried Blood	—5	—2	16	28	38	45	33	50
Hoof and Horn	0	7	18	—	36	49	43	55
Bone Meal	8	18	32	31	39	47	28	52
Guano	6	40	57	56	65	64	55	72
Ammonium Sulphate	16	44	58	66	77	80	59	89
Di-ammonium Hydrogen Phosphate	21	34	42	47	61	66	57	73
Urea	13	49	65	67	82	81	73	91

The results of series A show that urea was most rapidly and completely nitrified, followed closely by ammonium sulphate and guano. Ammonium phosphate nitrified less readily than the sulphate. Hoof and horn and dried blood were relatively slow at the start of nitrification, and with bone meal showed the lowest conversion to nitrate. Dried blood caused loss of nitrate at the start. The maxima were reached in 25 to 33 days, after which all samples showed a decrease in nitrate.

TABLE VIII
SERIES B. 180 P.P.M. NITROGEN

Fertiliser	4 Days	7 Days	12 Days	18 Days	25 Days	33 Days	46 Days	60 Days	Max. %
Dried Blood	-1	17	37	52	59	63	74	81	45
Hoof and Horn	9	32	49	51	80	96	112	108	62
Bone Meal	30	37	51	63	65	69	77	82	46
Guano	24	62	76	90	95	110	104	102	58
Ammonium Sulphate ...	42	62	61	113	116	126	141	165	92
Ammonium Phosphate ...	38	63	89	107	101	112	140	146	81
Urea	40	66	92	113	116	128	142	155	86

For series B, in the early stages of nitrification the data fall into two groups. Thus guano, urea, and the ammonium salts are rapidly transformed while dried blood, hoof and horn, and bone meal appear to be more resistant. The comparison of this grouping with the response to level of application data and chemical tests is given later in the Report. High values for percentage nitrified were shown by urea and the ammonium salts.

TABLE IX
SERIES C. 360 P.P.M. NITROGEN

Fertiliser	4 Days	7 Days	12 Days	18 Days	25 Days	33 Days	46 Days	60 Days	76 Days	Maxl. % Conver- sion
Dried Blood	17	31	52	90	114	143	180	190	145	53
Hoof and Horn	34	38	59	92	130	153	200	236	206	66
Bone Meal	36	46	60	64	72	102	123	128	120	36
Guano	49	89	92	105	125	150	160	172	165	48
Ammonium Sulphate ...	44	59	78	90	98	119	149	150	178	50
Ammonium Phosphate ...	58	75	97	115	148	163	224	244	251	70
Urea	56	80	109	131	160	178	240	260	274	76

Within the period of the experiment the relatively slow nitrification of ammonium sulphate when applied to this soil as a heavy dressing is in marked contrast to series A. This is apparently not due to the development of acidity. The relatively high nitrification of hoof and horn and dried blood is also shown. These substances show an increasing rate of transformation during two to three weeks, in contrast to the generally decreasing rates of urea, guano, and the ammonium salts.

The data of Tables VII, VIII, and IX show that in general the inorganic compounds, ammonium sulphate and phosphate, together with the pure organic compound urea, were more readily nitrified than the four commercial organic fertilisers. Of the latter group guano was the most rapidly nitrified while hoof and horn was superior to dried blood in this respect. The results for bone meal were of particular interest, in that despite its low values for maximum conversion to nitrate, in the early stages of reaction it surpassed both hoof and horn and dried blood. This is particularly marked in Table VII at the lowest level of application. Results for bone meal are further discussed in later sections of this Report.

In the preceding sections of this Report fertilisers have been compared on the basis of their total nitrate production after different intervals of time. The maximum percentage of nitrate formed differs widely, ammonium salts giving high values whereas fertilisers such as bone meal apparently contain a high proportion of nitrogen in forms not readily nitrified. If these maxima are regarded as a measure of nitrogen available for nitrification we can make a further comparison of fertilisers on this basis. The data for one experiment (series B) are recalculated in this way in Table X.

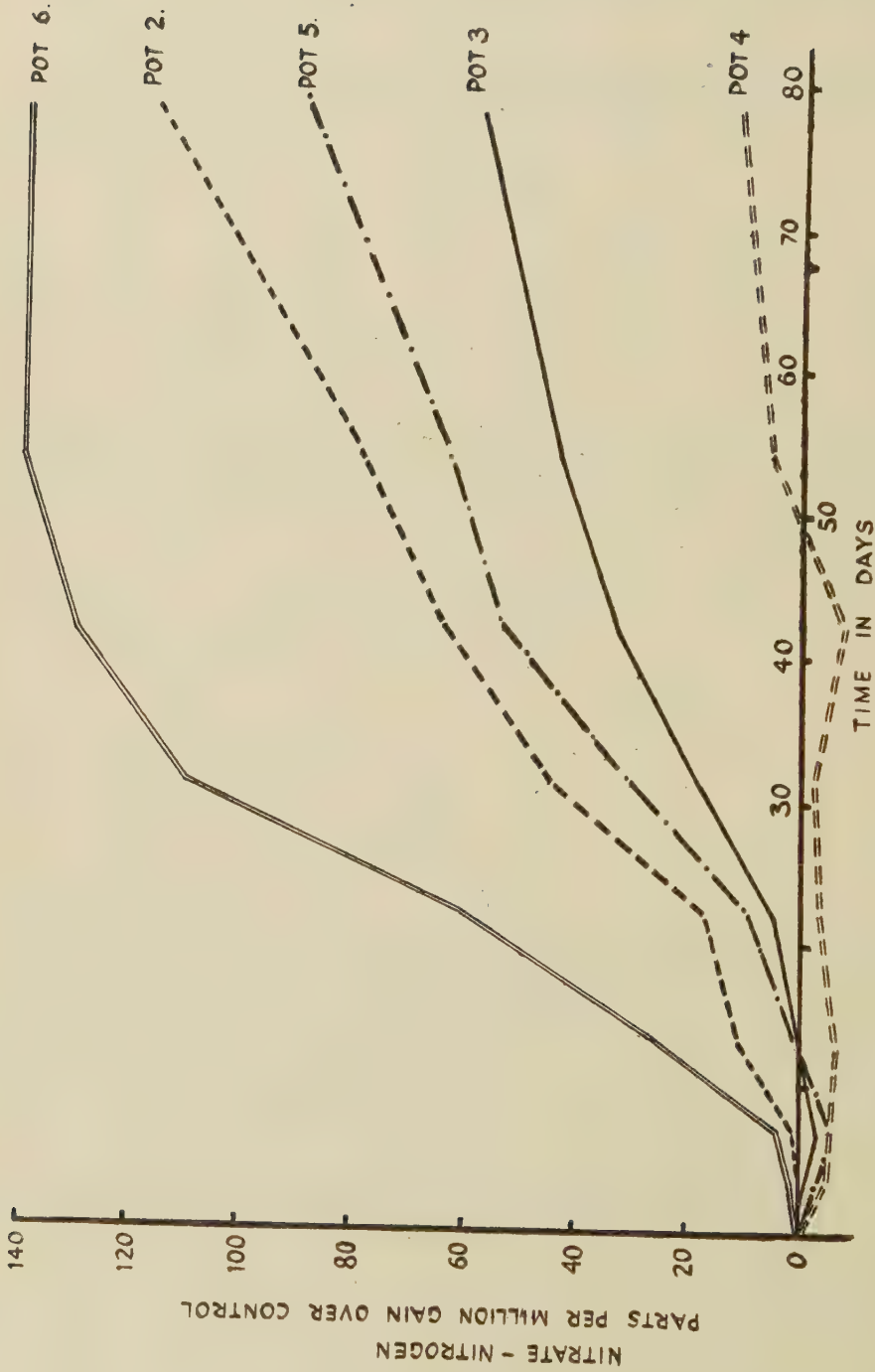


FIG. 2 The effect of phosphate on the nitrification of hoof and horn in a slightly acid soil.

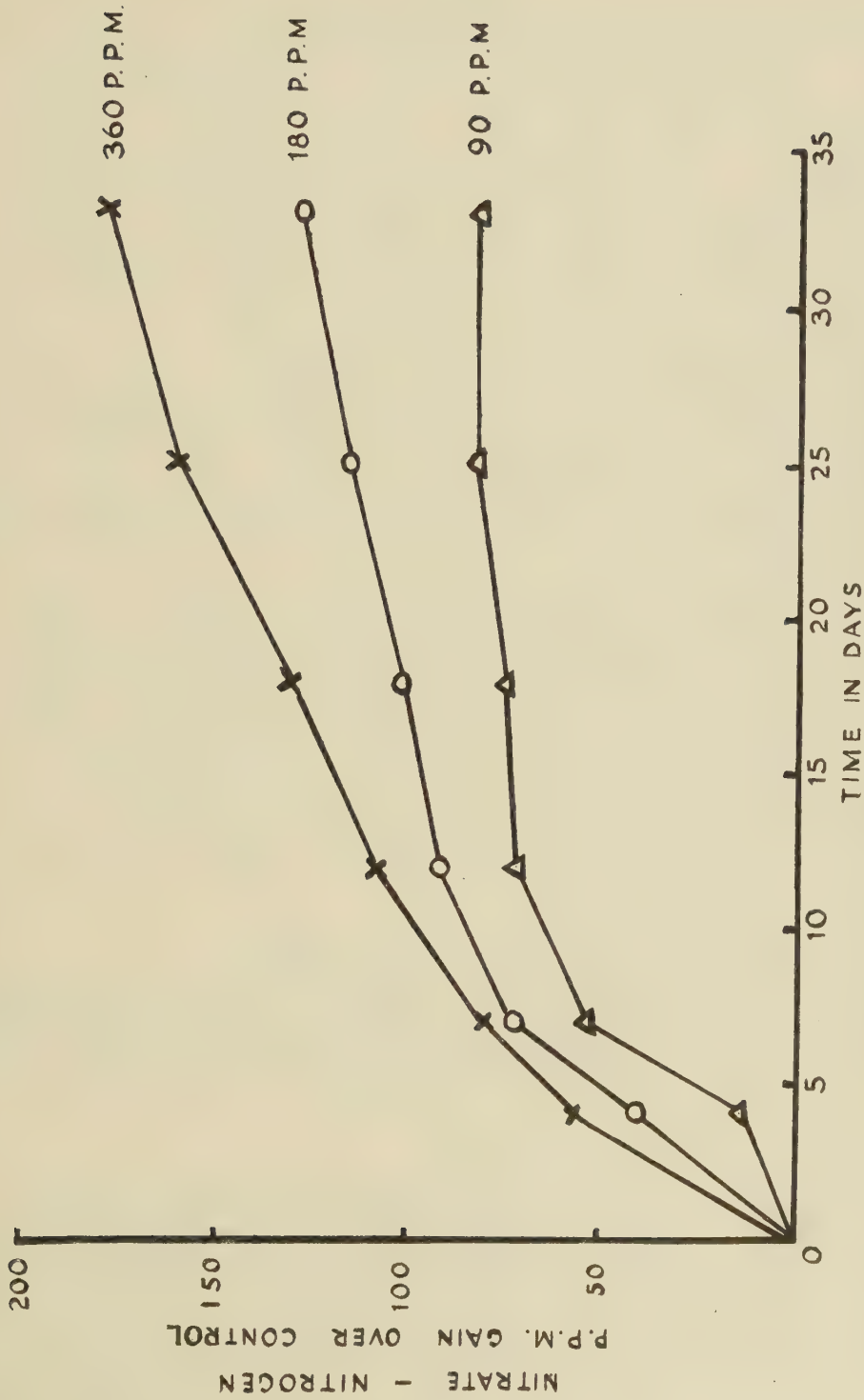


FIG. 3 Nitrification of urea at different levels of application, corresponding to additions of 90, 180, and 360 parts per million of nitrogen.

TABLE X
SERIES B

Nitrate produced as a Percentage of Maximum Found								
Fertiliser	4 Days	7 Days	12 Days	18 Days	25 Days	33 Days	46 Days	
Dried Blood	-1	21	46	64	73	78	90	
Hoof and Horn	8	30	45	47	74	86	100	
Bone Meal	36	45	62	76	78	93	94	
Guano	22	57	69	82	86	100	—	
Ammonium Sulphate	25	38	49	68	70	76	85	
Ammonium Phosphate	26	43	61	73	69	77	96	
Urea	26	43	59	66	75	83	91	

Conclusions from Table X and other data similarly treated are:—

- (1) The apparent differences between rates of nitrification of individual fertilisers are considerably reduced.
- (2) Dried blood and hoof and horn are still seen to be relatively inactive at the start.
- (3) Bone meal now appears as a substance readily nitrified (cf. Annual Report 1946, Owen and Rogers, p. 67 and Graph VI).

Certain disadvantages of this method of expression of nitrification data must, however, be noted. In particular the maximum conversion to nitrate cannot be taken as a general or analytical figure for any one fertiliser, but rather as a measure of availability under the conditions of each separate experiment.

Considerable uncertainty is involved in obtaining values for the maximum conversion to nitrate even when numerous analyses have been made. As will be seen from Table VII, these maximum values are not necessarily maintained for long periods but may be followed by rapid losses. Where heavy applications of inorganic fertilisers are made, approach to the maximum conversion to nitrate may be slow. This is shown in Table IX, particularly by ammonium sulphate. Difficulties thus arise in maintaining the moisture content of the soil over long periods without alteration in its physical condition. Attempts have frequently been made to assess the availability of nitrogenous fertilisers by one or two nitrate determinations after an arbitrary period of incubation. Apart from the difficulties already discussed, such determinations are likely to lead to erroneous conclusions owing to differences in the form of the reaction curves. This is illustrated by the data for hoof and horn in Figs. 1 and 2. In Fig. 1 the rate of nitrification fell as the experiment progressed and the data can be fitted to a first order equation of the form:—

$$\log (A - x) = -kt + C$$

where x is the amount of nitrate formed in time t ,

A is the maximum conversion to nitrate and C is a constant.

Fig. 2 shows the nitrification of the same fertiliser in presence of di-potassium hydrogen phosphate (top curve), from which it is seen that the rate of nitrification increased with time throughout the first four weeks. This type of curve is typical of an autocatalytic reaction as was shown to apply to nitrification data in the soil by Miyake² (1916). The central portion of such a curve is very steep and here a difference of two or three days in the selection of an arbitrary incubation period would lead to very different results.

Response to Level of Application of Fertilisers

Tables VII to IX also provide data for the comparison of three different levels of application of seven fertilisers. In general, as expected, the nitrate concentrations in the soil at any time during nitrification increase with the quantity of fertiliser added. This is illustrated in Fig. 3 for urea. A more interesting relationship appears when data for percentage nitrified are compared. Thus of the substances which nitrify readily at the start, urea, ammonium sulphate and guano show widely different percentages nitrified for the three levels of application. Data for urea are given in Fig. 4. A very different relationship appears for dried blood and hoof and horn, substances which are nitrified slowly at first. Here the percentage nitrified does not differ very markedly with level of application at any time of sampling during the reaction. The form of these curves is similar to that already given for hoof and horn in Fig. 1, and will be referred to subsequently as of type II, in contrast to type I exemplified by urea. Ammonium phosphate and bone meal gave results somewhat

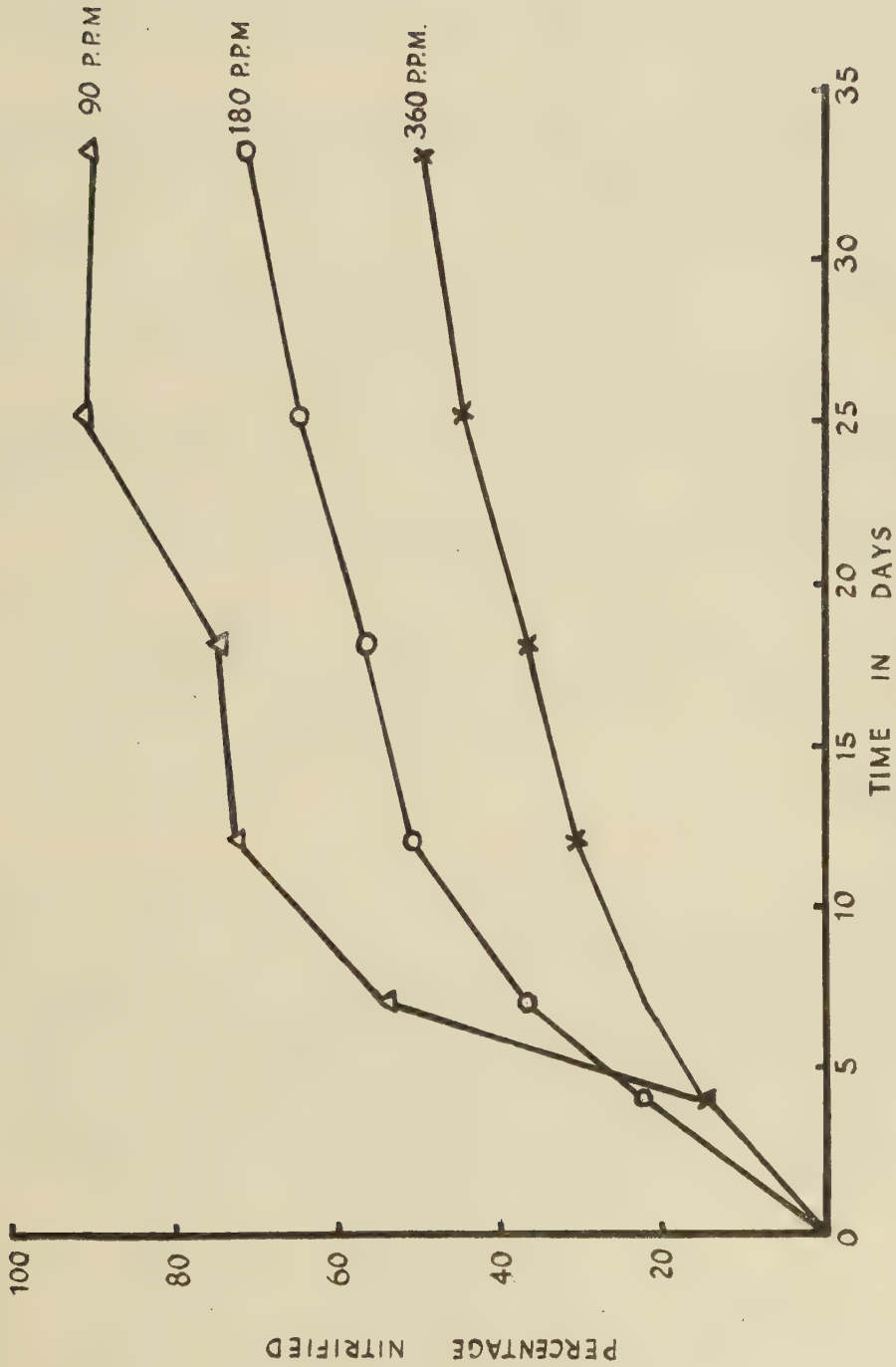


FIG. 4 Urea. The percentage nitrified at different levels of application.

intermediate between types I and II; in both cases the percentage nitrified differed markedly between the 180 and 360 p.p.m. applications of nitrogen, but less definitely so between 90 and 180 p.p.m.

The results suggest a fundamental difference in the mechanism of decomposition of the two groups of fertilisers. It is likely that this is related to their chemical structure, as briefly indicated below, graphs of type II being accompanied by a preliminary breakdown of highly complex materials prior to nitrification:—

Type I

- Ammonium Salts ... Available for immediate conversion to nitrite and nitrate.
 Urea. $\text{CO}(\text{NH}_2)_2$... A simple organic compound containing two amino-groups in the molecule.
 Guano ... A complex mixture containing much non-protein nitrogen such as uric acid.

Type II

- Dried Blood } ... Crude protein materials, containing the relatively resistant schleroproteins such as fibrin and keratin. The nitrogen in these substances is thus in forms more complex than those of the previous group.
 Hood and Horn }

A Preliminary Test of the Nitrogen in Organic Fertilisers

Samples of four commercial fertilisers, with urea for comparison, were distilled with an aqueous suspension of magnesia into N/10 hydrochloric acid. This test is similar to that given in the Fertilisers and Feeding Stuffs Regulations, 1932, for nitrogen in the forms of ammonium salts in presence of organic matter. The results, in which ammonia-nitrogen ($\text{NH}_3\text{-N}$) liberated is expressed as a percentage of the total nitrogen content of the substance, are given, in Table XI.

TABLE XI

Fertiliser	% N liberated as Ammonia	Nitrification in Soil					
		Nitrate formed in 7 Days ($\text{NO}_3\text{-N}$)			Nitrate formed in 12 Days ($\text{NO}_3\text{-N}$)		
		A	B	C	A	B	C
Dried Blood ...	1.1	—2	10	9	18	—	14
Hoof and Horn ...	3.4	8	18	11	20	27	16
Bone Meal ...	8.0	20	21	13	36	28	17
Guano ...	31.6	44	35	22	63	42	66
Urea ...	60-70	49	66	80	65	92	109

The nitrification data are taken from series A, B, C, of the previous section.

Duplicate determinations gave good agreement for the four commercial fertilisers. With urea the rate of completion of reaction was low, ammonia being evolved even after collecting 250 ml. of distillate; cyanate ions were present in the digest. It will be seen from Table XI that the order of nitrate formation in the six columns is in every case the same as that of the chemical test. As expected, the crude protein fertilisers such as dried blood and hoof and horn do not yield much ammonia in this test, but guano gives a relatively high value. The chemical nature of the nitrogen compounds decomposed under these conditions is not yet known. When tested similarly asparagin, the amide of aminosuccinic acid ($\text{CO}_2\text{H} \cdot \text{CH}(\text{NH}_2) \cdot \text{CH}_2 \cdot \text{CO} \cdot \text{NH}_2$), yielded only traces of ammonia; it would therefore seem that the digestion and distillation are by no means drastic.

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2. THE DETERMINATION OF AVAILABLE NUTRIENTS IN TOMATO SOILS. THE EFFECT OF SOIL NUTRIENTS ON THE PLANT.

by J. LITTLEWOOD and O. OWEN

Previous reports have already dealt with the results given by different methods of extraction for the estimation of "available" potash and phosphoric acid. Purely on an analytical basis it was concluded that there is little to choose between the several methods examined. Where potash is finally determined by the perchloric acid method, Truog's extracting solution and Morgan's solution are ruled out for reasons given on page 96. Of the remaining methods used, viz., 1 per cent. citric acid, N/2 acetic acid and distilled water, the balance is in favour of the N/2 acetic acid as recommended by Rice Williams¹. For the determination of phosphate there are no analytical difficulties as there are in the case of potash and any of the extractants can be used. Again, however, N/2 acetic acid was considered to be the most satisfactory.

To complete the picture it was considered desirable to determine whether the results given by any of the methods could be correlated with the dry weights of the plants produced and/or the actual uptake of nutrients by the plant. In this way it was possible to obtain some information about the effects of the nitrogen status in the soil and nitrogen in the plant. This report deals with these aspects of the problem.

Experimental

For the experiment 15 soils which were available on the nursery here were used. Strictly speaking, they cannot all be described as tomato soils but they are the types which are encountered in tomato growing and they were chosen to provide as wide a variety as possible. Briefly they are described as follows:—

- A. Old cucumber bed; rich in organic matter; such as is frequently used as a basis for propagating mixtures for tomatoes.
- B. Maiden loam; low in organic matter; yellow type with a fair amount of clay, a soil which might be used for propagating work, probably very suitable for carnation culture.
- C. Old loam rich in turf residues; dark coloured; would be considered suitable for propagating or for soil replacement.

The following were soils in which tomatoes have been grown continuously for 30 years. Originally the soil was a rather hungry maiden loam. The main nutrient characteristics are as shown:—

- H.4, P.1. Low organic matter and low nitrogen.
- H.4, P.2. Low organic matter and low in nutrients generally.
- H.4, P.5. Complete manurial treatment, but somewhat low in organic matter.
- H.4, P.8. Complete inorganic fertilisers and low organic matter.
- H.4, P.9. Low organic matter and low phosphate.
- H.4, P.10. Low organic matter and low potash.

The three following soils had not been cultivated for such long periods:—

- H.5, P.5. Cultivated for 25 years with fairly liberal dressings of fertilisers and organic matter.
- H.7, P.4. Cultivated for 25 years with complete nutrients including heavy dressings of muriate of potash in recent years. Yields good crops.
- H.11, P.2. Cultivated for 12 years. Well manured and yields good crops.

The remaining soils were odd ones which were available on the nursery:—

- S.C.H. Soil which has probably been overmanured for experimental work; high in nutrients and organic matter.
- R.P.I. An old tomato soil exposed to the weather.
- M.C. Poor soil to be used for casing mushrooms.

Some analytical data for the soils are shown in Table I.

Potash in the soil was estimated by solubility in the three extractants used and phosphoric acid in the five extractants. Total nitrogen was determined by the usual Kjeldahl method and nitrate-nitrogen in aqueous extracts by the phenoldisulphonic acid method.

The actual experiment consisted of growing young tomato plants in these 15 different soils.

The variety used was Potentate, a variety which is widely grown in commercial glasshouses. The seedlings were grown in normal potting soil in size "60" pots until they reached the stage of

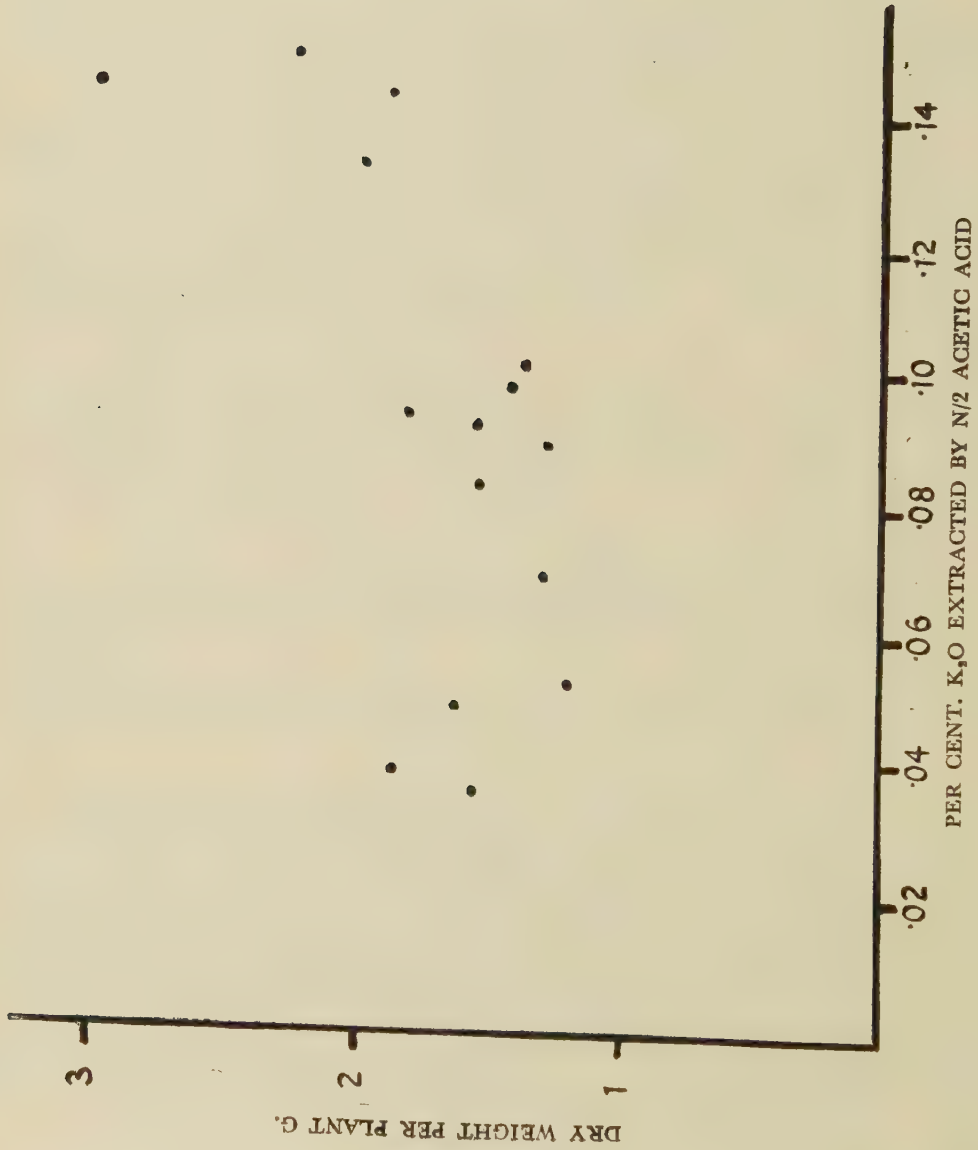


FIG. 1

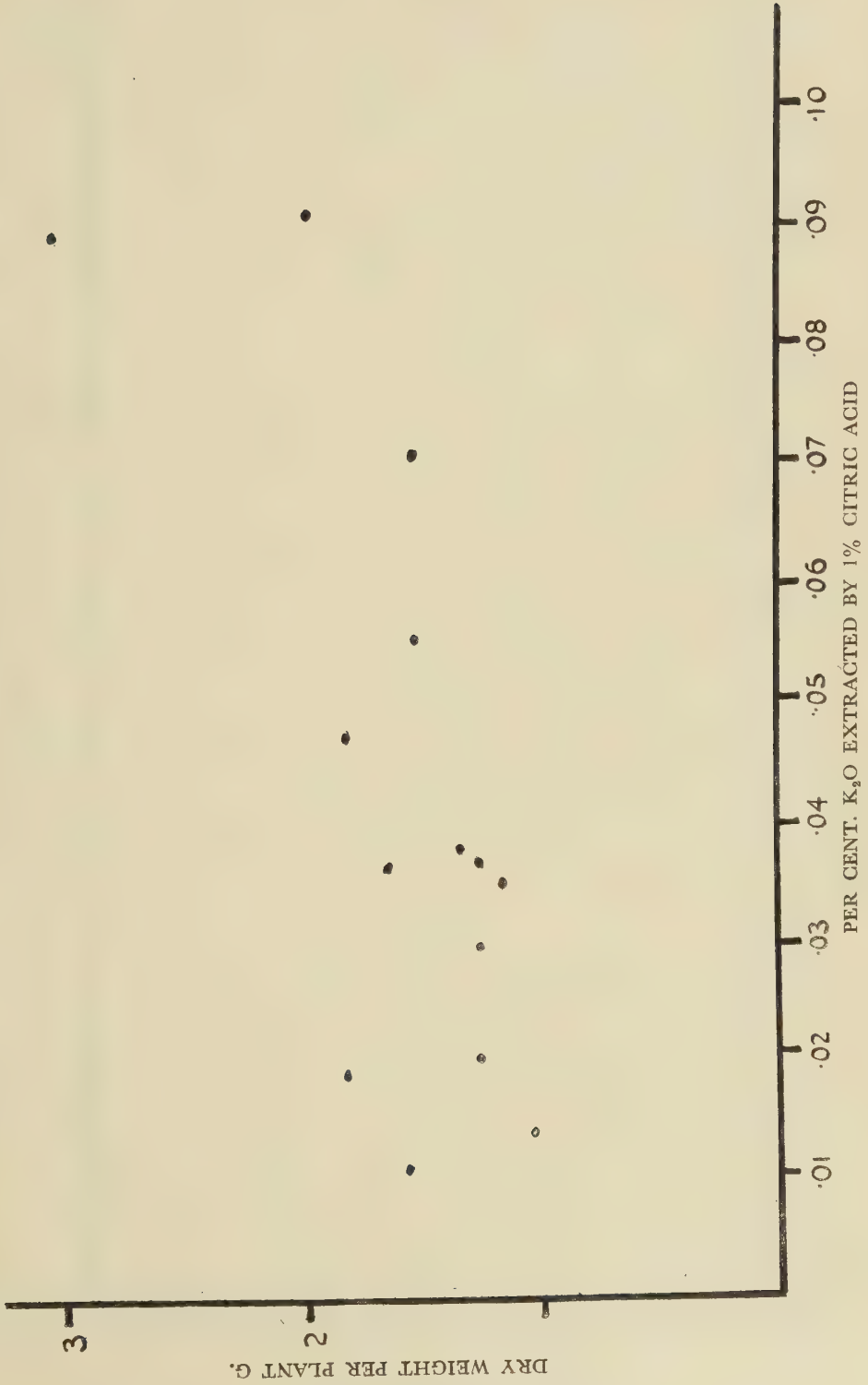


FIG. 2

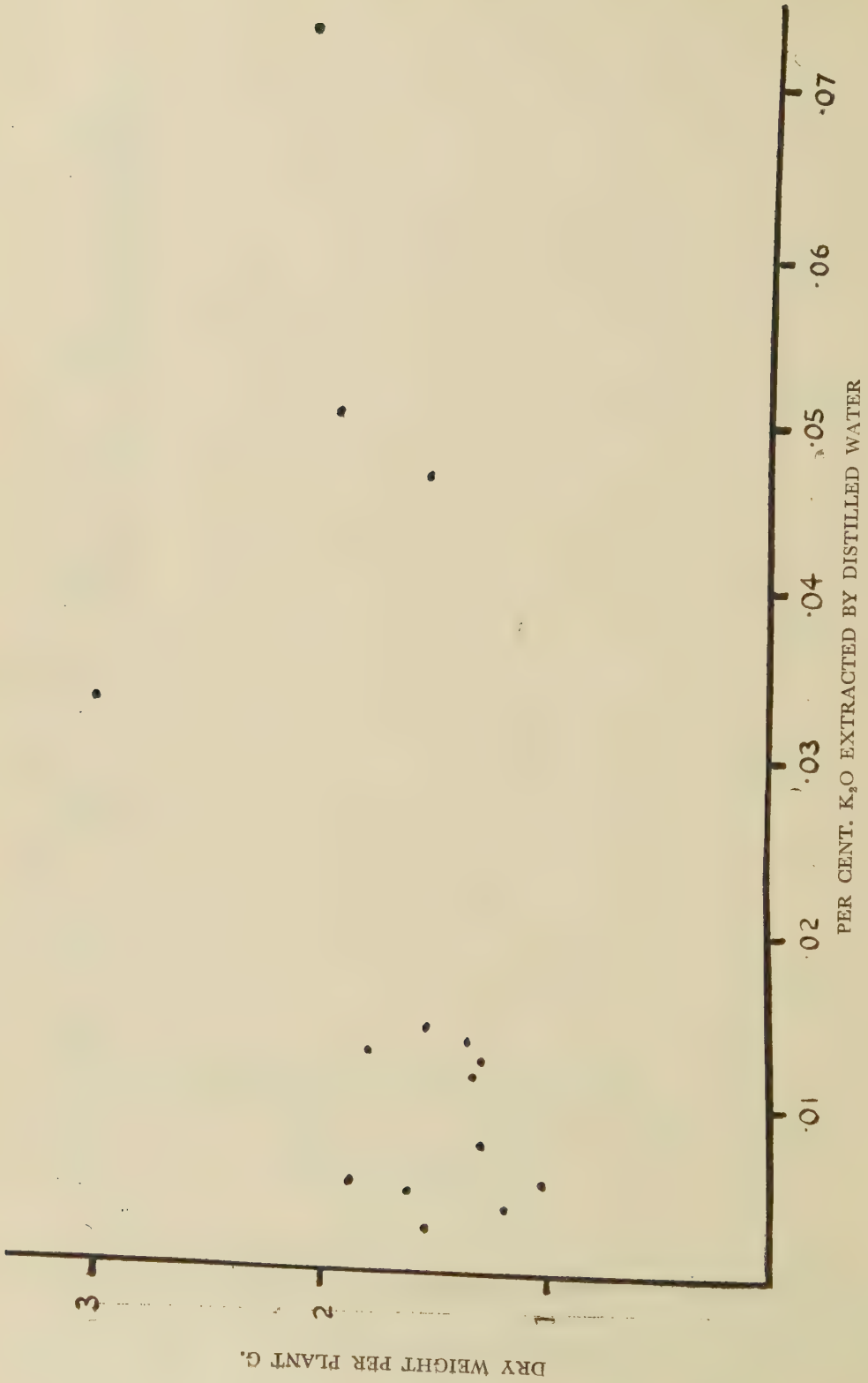


FIG. 3

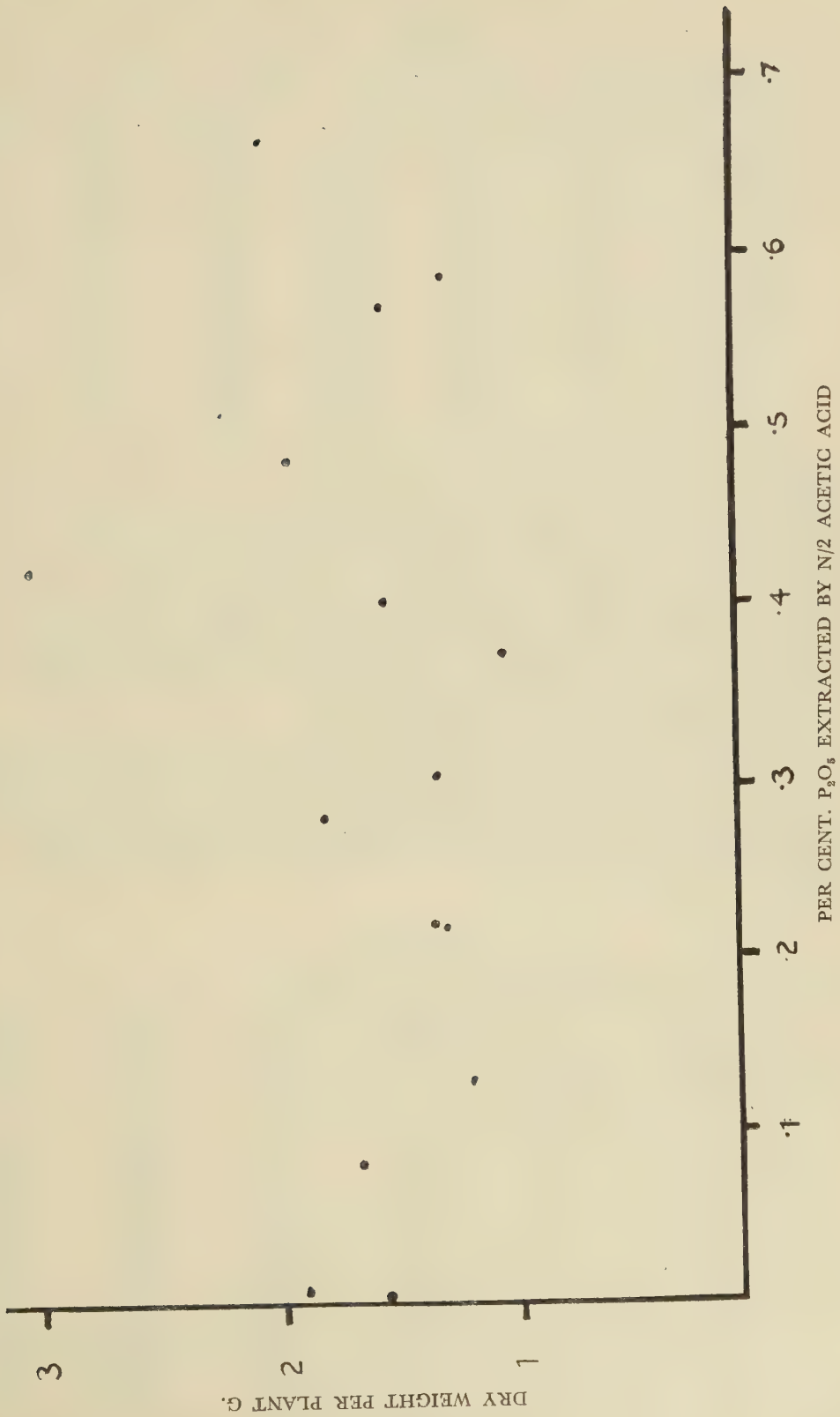


TABLE I

SOIL DATA

Soil	Moisture Wet Soil	Moisture Air-dry Soil	CaCO ₃	Org. C.	% Nitrogen	C/N. Ratio	NO ₃ -N. p.p.m.
A	31.97	7.97	1.861	6.032	.6682	9.02	630
B	20.99	3.56	.3687	2.976	.3357	8.86	42
C	32.88	10.97	.4565	6.266	.7254	8.65	193
H4P1	16.62	2.46	4.641	1.100	.1303	8.47	15
H4P2	15.69	2.37	2.900	1.366	.1683	8.10	7
H4P5	22.12	3.49	1.944	2.384	.2595	9.20	29.5
H4P8	22.26	3.56	5.164	2.305	.2390	9.62	11
H4P9	20.71	3.28	5.289	1.416	.1729	8.19	15
H4P10	21.13	3.27	4.594	1.386	.1498	9.26	11
H5P5	23.60	4.53	2.008	2.655	.3174	8.36	8
H7P4	21.41	4.07	1.280	2.750	.2961	9.30	23
H11P2	21.93	3.40	.876	2.536	.2732	9.29	40
S.C.H.	23.71	4.27	3.312	2.846	.3353	8.49	151
R.P.1	24.90	5.39	2.026	1.286	.1706	7.52	13.7
M.C.	16.65	4.17	2.320	1.693	.1818	9.35	99

three pairs of broad leaves. The soil was then removed from the roots, and as much as possible of that adhering to the rootlets was washed off without doing damage. They were then potted up into the 15 soils listed above in size "32" pots, 14 plants being potted into each soil.

During the growth of the plants care was taken to ensure that each plant received as far as possible the same treatment. They were grown on a low staging in one of the cucumber houses and the plants were moved frequently to avoid any localisation of light and temperature. Watering was carried out with care so as to avoid loss of soluble nutrients by leaching and each pot received the same amount each day. Distilled water was used for watering to avoid addition of any nutrients which are present in tap water. Initially it was sufficient to give each plant 50 mls. once per day, but this had to be increased to twice per day after two weeks.

The plants were harvested at the end of 30 days. Sampling in all cases was done near soil level, where the cotyledons had been attached to the stems and was carried out early in the day before the plants showed any tendency to wilt. They were weighed immediately for their fresh weight and then dried at 105° C. to constant weight. The dried tissue was ground to pass a 1 mm. sieve. This material was used for all determinations, and is the basis for all calculations. Nitrogen determinations were carried out directly on this material and the other determinations on the ash. The nitrogen contents of the tissue samples are shown in Table II.

TABLE II

PLANT TISSUE AND NITROGEN DATA

Soil	Total Dry Weight of Plant Tissue g.	No. of Plants	Average Dry Weight per Plant g.	% Nitrogen in Dry Matter	Weight Nitrogen per Plant g.	Corrected Nitrogen Value g.
A	39.5	13	3.04	3.824	.1160	.0967
B	26.24	14	1.87	3.114	.0581	.0338
C	21.56	14	1.54	3.514	.0540	.0347
H4P1	18.50	14	1.32	1.834	.0241	.0048
H4P2	16.52	13	1.27	2.118	.0269	.0076
H4P5	25.12	14	1.79	2.518	.0451	.0258
H4P8	15.22	12	1.27	2.118	.0269	.0076
H4P9	18.61	14	1.33	2.176	.0290	.0097
H4P10	14.20	14	1.02	2.601	.0265	.0072
H5P5	21.27	14	1.52	2.091	.0318	.0125
H7P4	26.79	14	1.91	2.800	.0535	.0304
H11P2	21.25	14	1.52	2.716	.0414	.0183
S.C.H.	28.24	14	2.02	3.772	.0760	.0530
R.P.1	15.40	13	1.19	2.288	.0273	.0042
M.C.	21.00	13	1.62	3.713	.0601	.0370

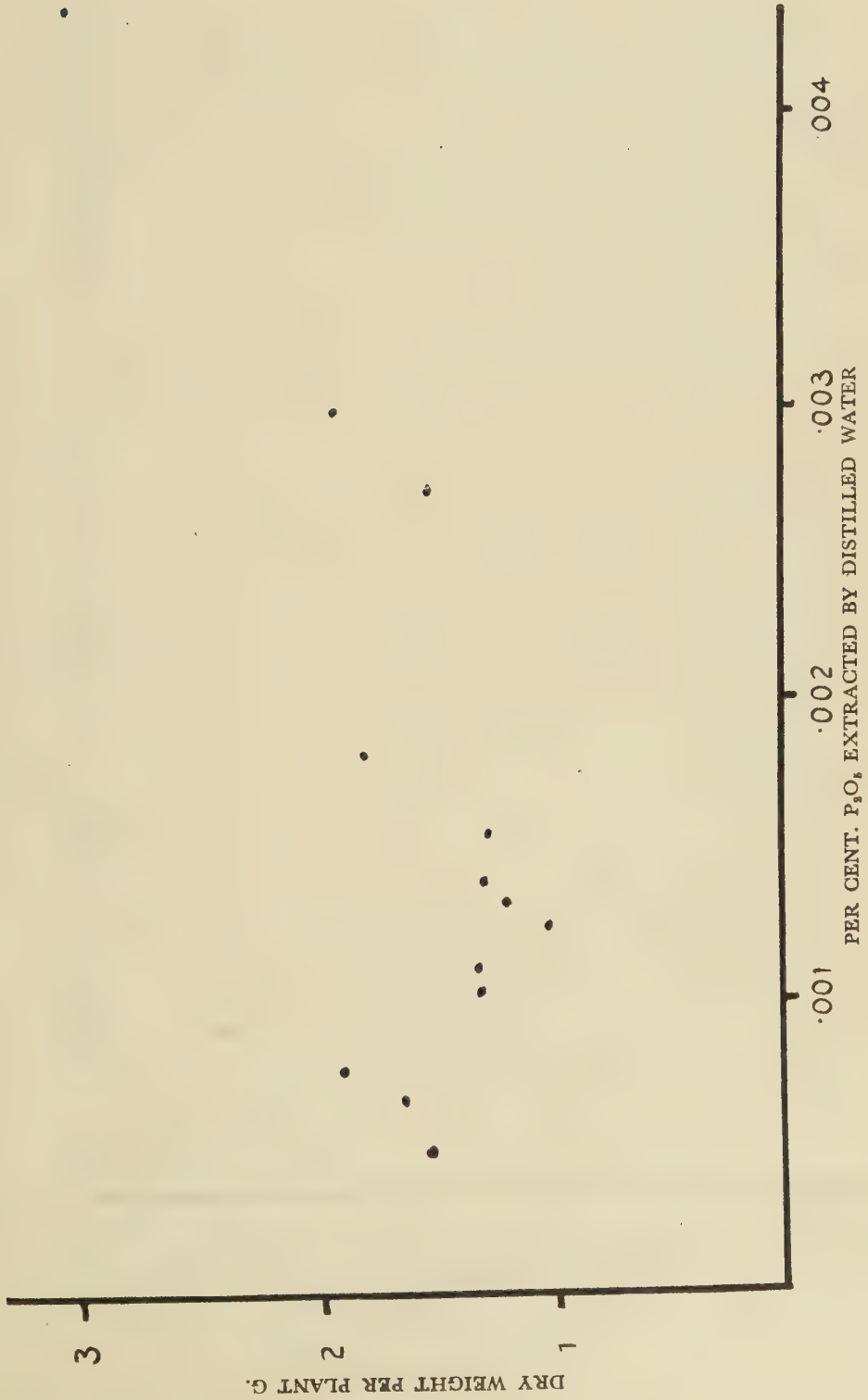


FIG. 5

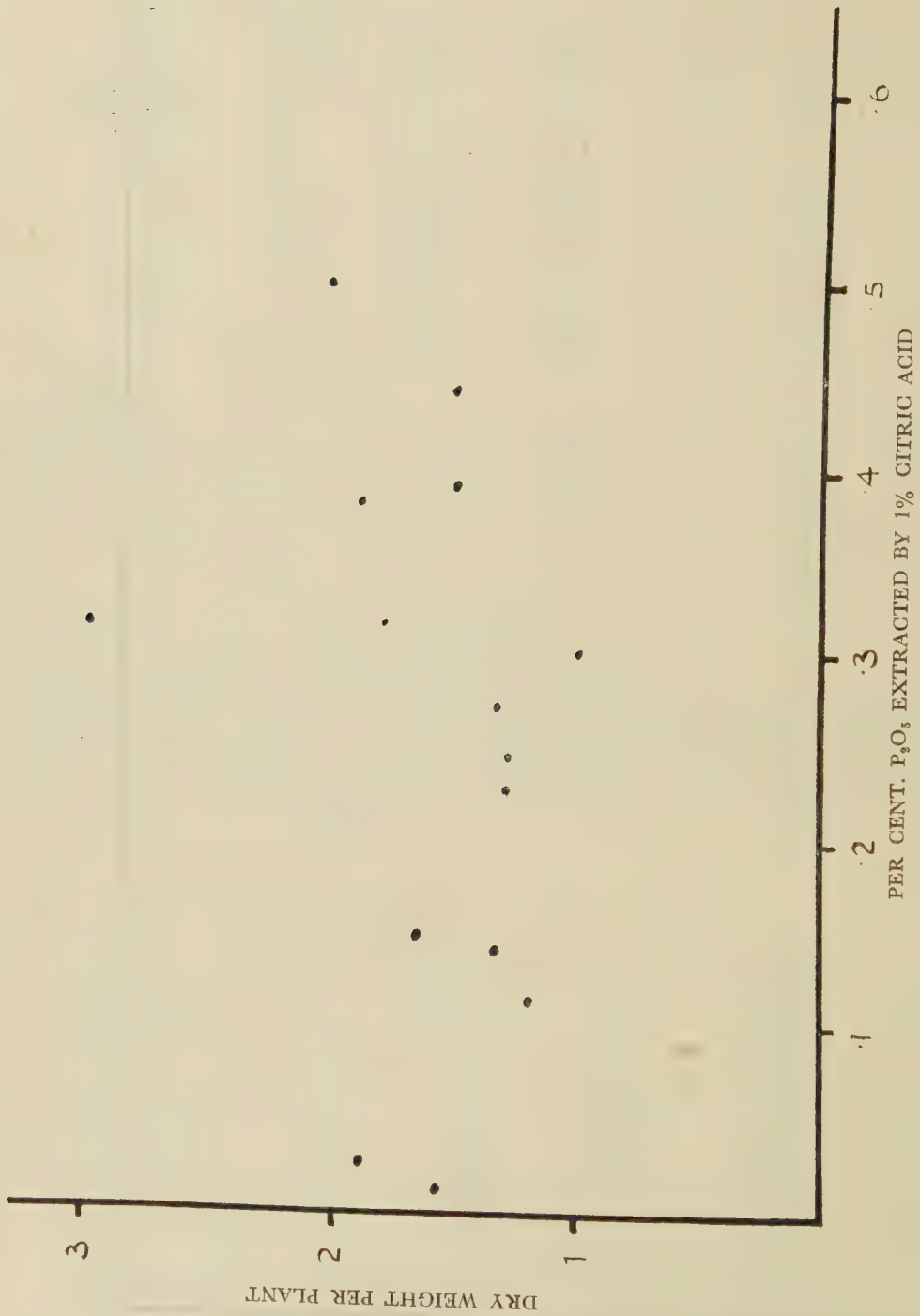
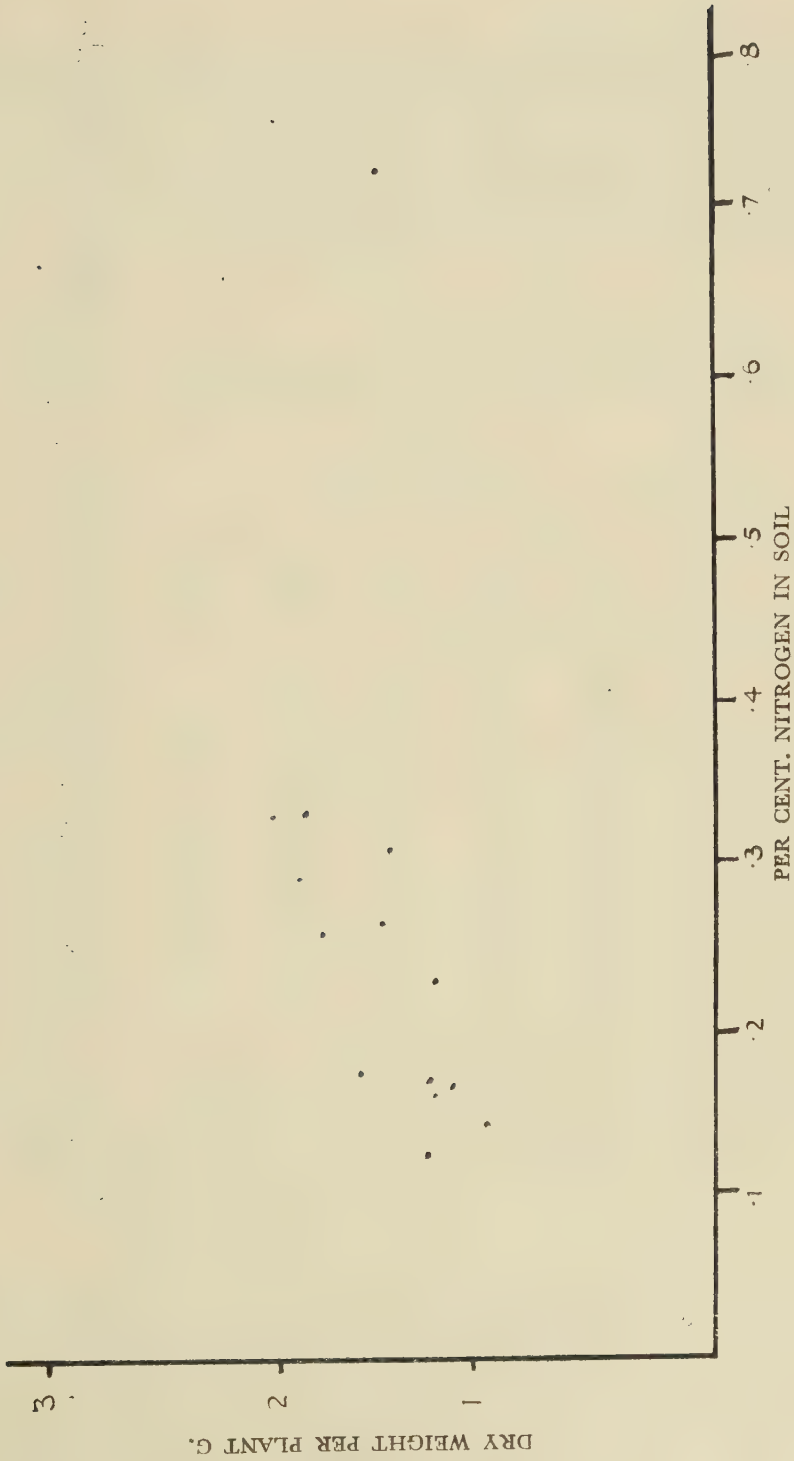


Fig. 6



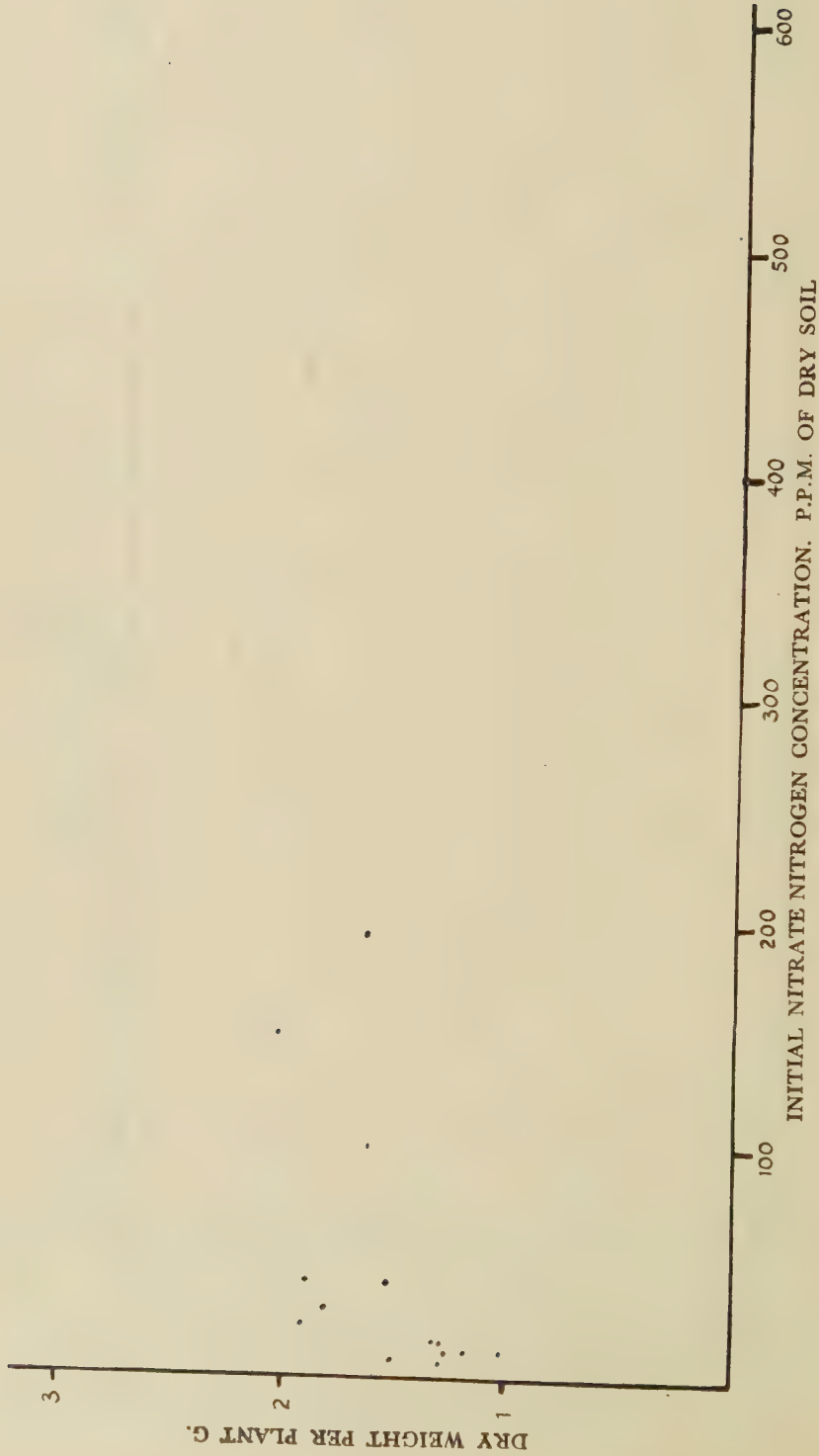


FIG. 8

Representative samples of the young plants were analysed at the commencement of the growing experiment and values so obtained were used as a correction on the final values obtained at the end of the experiment.

The Results

For the evaluation of the data obtained two criteria are important. The one is the amount of plant tissue actually produced during the growth period under review. This is probably the most important and fortunately is easily measured by the dry weight. The other is the actual uptake of nutrients by the plant. This is important from at least two points of view. In the first place, the actual composition must be of consequence in the actual economy of the plant. Secondly, experience has shown that potash uptake in the tomato is of importance in the early stages of growth on account of its effect on the quality of the fruit. At the same time it should be remembered that it is unwise to place too much emphasis on any single constituent as all are liable to be influenced by other constituents. (Cf. phosphate and potash, Owen².)

1. Dry Matter Production

Tables II to IV record, *inter alia*, the dry weights of plants grown in the experiments and these values are plotted against some of the individual nutrients in Figs. 1 to 7. In Figs. 1 to 3 dry weights

TABLE III
POTASH RESULTS

Soil or Plant Tissue	1% Citric Acid mgm %	N/2 Acetic Acid mgm %	Distilled Water mgm %	Total Dry Weight	No of Plants	Weight per Plant g.	Ash %	% K ₂ O in Dry Matter	Weight K ₂ O per Plant g.	Corrected Weight K ₂ O per Plant g.
A.1 \ ...	Seedlings: Analyses for correction			6.12	14	.43	18.52	4.8	.0207	
A.2 \ ...				7.10	14	.51	20.95	4.97	.0250	
A	89.1	145.0	34.5	39.5	13	3.04	24.85	8.511	.2587	.2357
B	19.1	38.1	5.3	26.4	14	1.87	22.06	5.733	.1072	.0842
C	11.7	36.6	2.8	21.56	14	1.54	18.90	2.373	.0370	.0140
H4P1 ...	36.8	100.4	11.8	18.50	14	1.32	19.89	6.009	.0793	.0563
H4P2 ...	20.7	69.7	7.5	16.52	13	1.27	17.60	2.977	.0378	.0158
H4P5 ...	47.2	93.0	13.2	25.12	14	1.79	26.8	7.068	.1266	.1036
H4P8 ...	30.4	88.2	12.9	15.22	12	1.27	25.5	6.615	.0840	.0610
H4P9 ...	37.1	99.9	13.8	18.61	14	1.33	20.25	6.76	.0898	.0668
H4P10 ...	13.5	77.3	5.3	14.20	14	1.02	17.22	2.871	.0290	.0060
H5P5 ...	56.0	92.5	47.3	21.27	14	1.52	20.27	6.253	.0950	.0720
H7P4 ...	91.2	143.3	51.2	26.79	14	1.91	22.15	8.337	.1592	.1362
H11P2 ...	71.8	83.0	14.4	21.25	14	1.52	21.37	6.972	.1059	.0829
S.C.H. ...	230.4	132.3	74.3	28.24	14	2.02	23.02	7.492	.1521	.1291
R.P.I. ...	35.0	53.2	3.7	15.40	13	1.19	19.7	4.480	.0529	.0299
M.C. ...	37.3	49.7	4.8	21.00	13	1.62	24.02	4.576	.0737	.0507

are plotted against potash extracted by the three solutions. These indicate that there are positive correlations between dry weight and potash extracted from the soil in each. That this is so is shown by the values calculated for the correlation coefficient *r*. The values for *r* are as follows:—

Extractants for K ₂ O				<i>r</i>
N/2 Acetic Acid	...	...	...	.54
1 per cent. Citric Acid	...	...	...	.50
Distilled Water	...	...	...	.49

Differences in the value of *r* are slight but it is satisfying that the N/2 acetic acid gives the best values in view of the fact that we had already preferred this extractant on analytical grounds.

In Figs. 4 to 6 are plotted dry weights against the phosphoric acid extracted from the soil.

There is no significant correlation between dry matter produced and phosphate extracted by Truog's solution.

In Fig. 4 are plotted dry matter values against phosphoric acid extracted by N/2 acetic acid. Distribution of points suggests little correlation is likely to exist between these two quantities. Actually, the value for *r* here is .18 which is not significant.

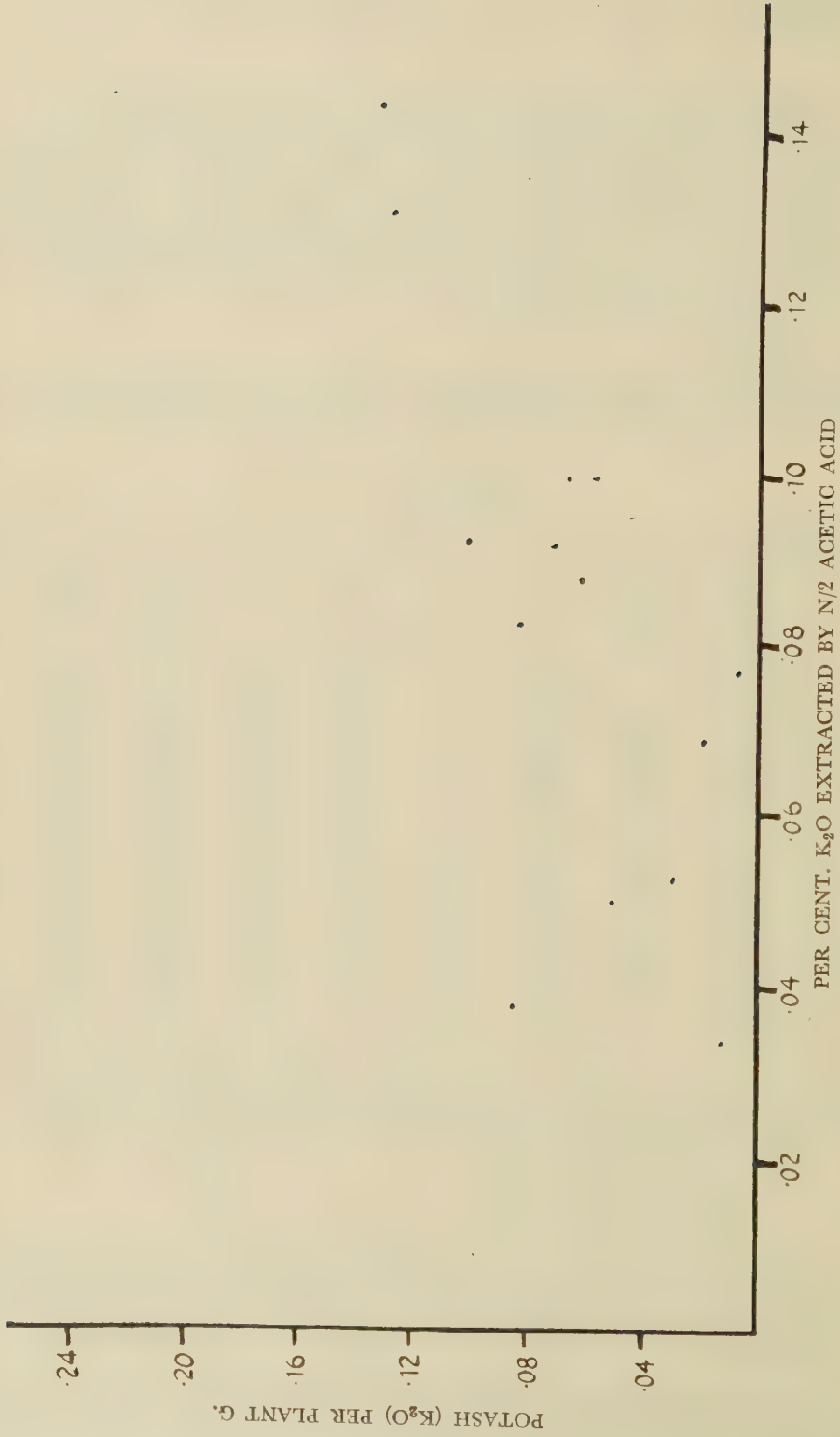


FIG. 9

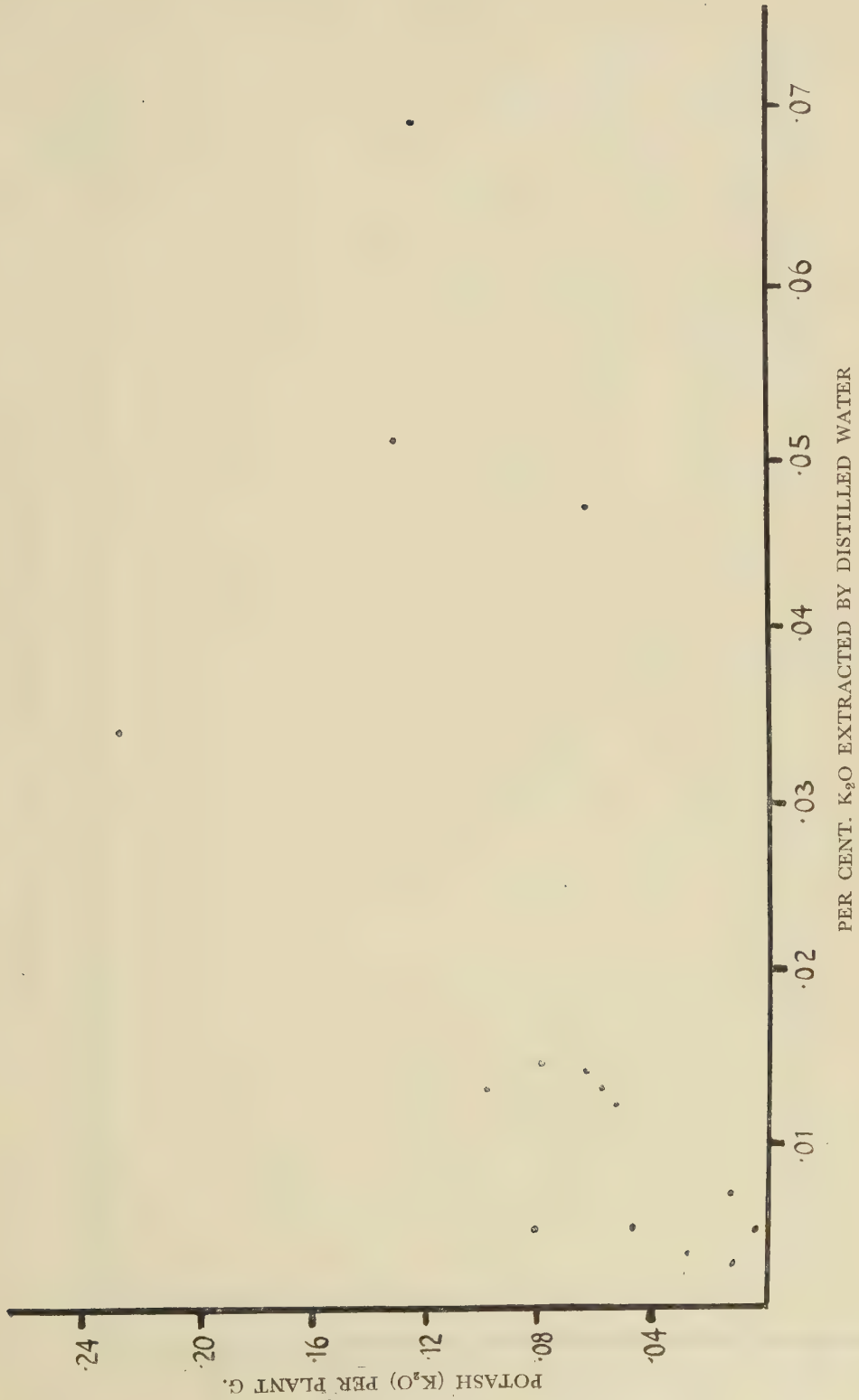


FIG. 10

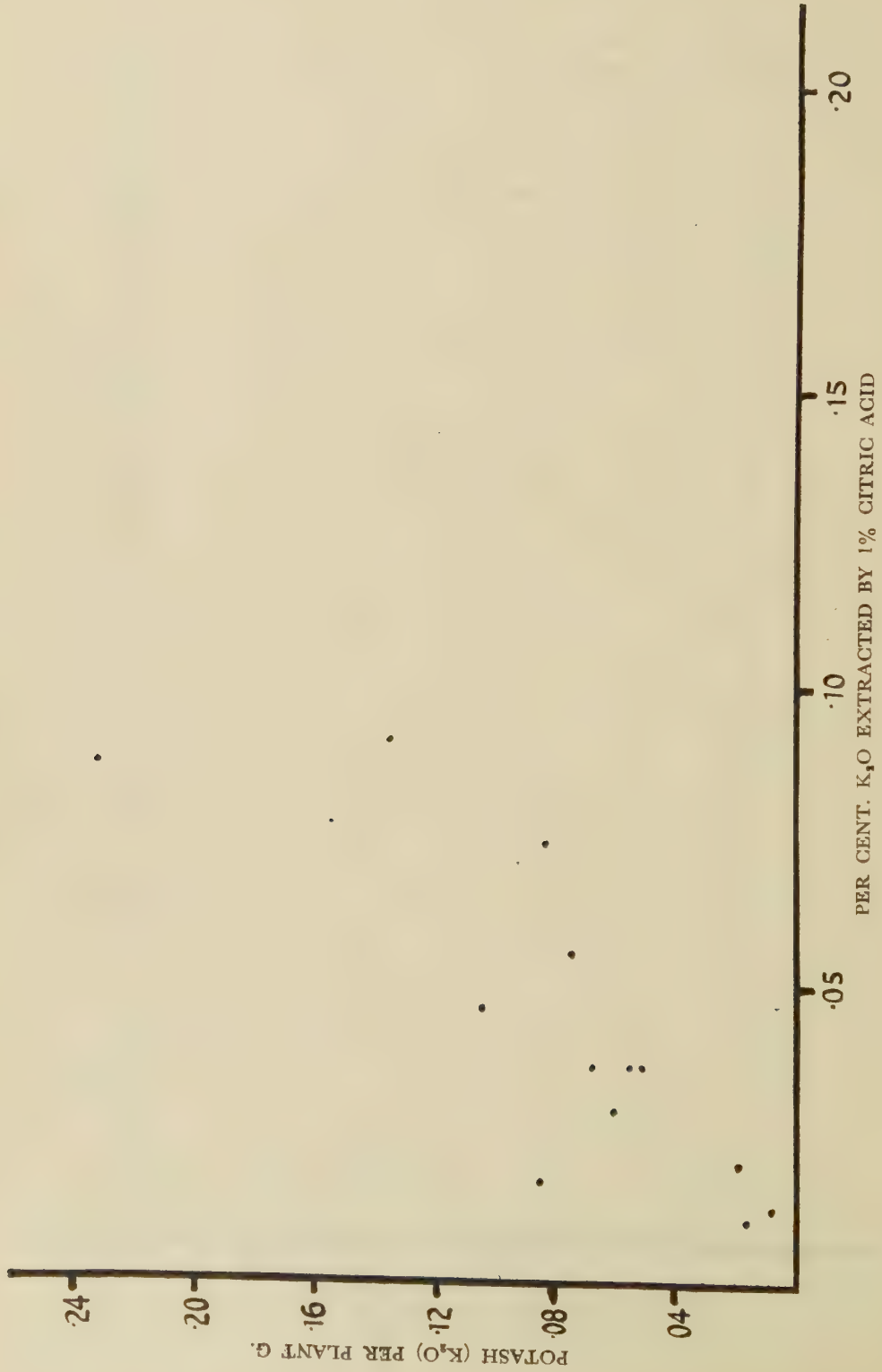


FIG. 11

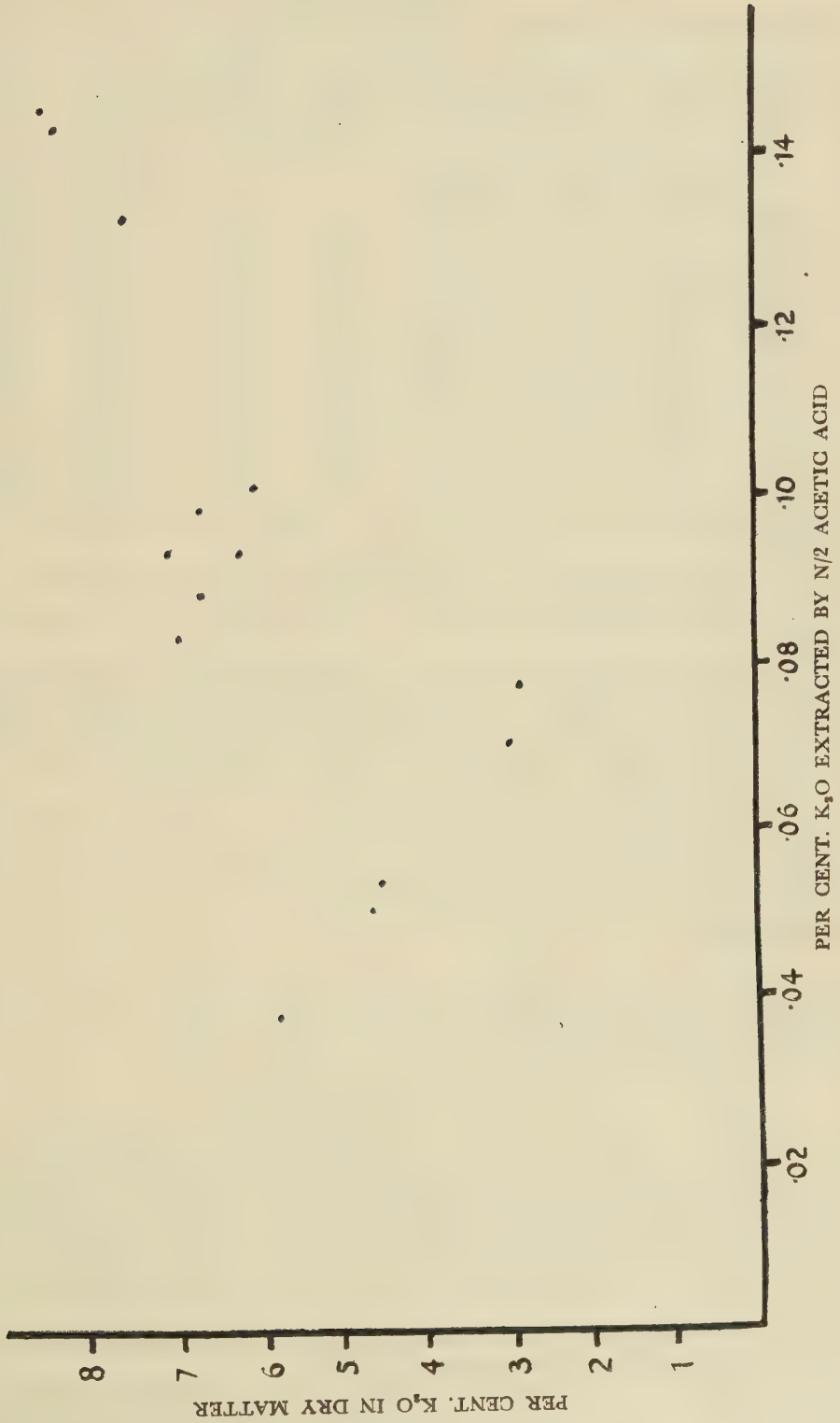


Fig. 12

TABLE IV
PHOSPHATE RESULTS

Soil or Plant Tissue	1% Citric Acid. mgm. %	N/2 Acetic Acid. mgm. %	Distilled Water. mgm. %	Morgan's Solution. mgm. %	Truog's Solution. mgm. %	Dry Weight per Plant. g.	% P ₂ O ₅ in Dry Matter	P ₂ O ₅ per Plant. g.	Corrected Weight P ₂ O ₅ per Plant. g.
A.1\ ...	Seedlings: Analyses for correction.					.43	-.8962	-.00386	
A.2\ ...						.51	-.9378	-.00478	
A ...	320.6	421.7	4.3	144.5		3.04	-.9628	-.0293	-.0255
B ...	27.0	9.3	.77	5.2	3.5	1.87	-.4513	-.00844	-.0046
C ...	13.5	4.5	.45	4.4	1.3	1.54	-.4298	-.00660	-.0028
H4P1 ...	276.8	303.7	1.07	147.7	359.1	1.32	-.5650	-.0074	-.0036
H4P2 ...	230.5	213.0	1.38	111.7	207.0	1.27	-.5690	-.00722	-.0034
H4P5 ...	320.6	277.0	1.8	91.2	319.2	1.79	-.9473	-.0169	-.0131
H4P8 ...	245.6	588.0	1.55	205.5	607.8	1.27	-.5718	-.00727	-.0034
H4P9 ...	144.2	215.0	1.03	74.0	200.6	1.33	-.4460	-.00592	-.0021
H4P10 ...	302.4	372.0	1.24	192.3	366.1	1.02	-.4320	-.00435	-.0005
H5P5 ...	447.8	565.0	2.72	130.0	562.4	1.52	-.6960	-.0106	-.0059
H7P4 ...	387.2	479.0	2.97	105.2	604.9	1.91	-.5880	-.0112	-.0065
H11P2 ...	397.6	406.0	4.65	114.0	476.2	1.52	-.9495	-.0144	-.0097
S.C.H. ...	505.4	660.0	13.05	249.0	698.1	2.02	1.049	-.0212	-.0165
R.P.1 ...	119.0	127.0	1.32	46.5	152.3	1.19	-.6002	-.00715	-.0024
M.C. ...	154.9	79.0	.64	240.0	152.4	1.62	-.4138	-.00671	-.0020

The distribution of points in Fig. 5, on the other hand, indicates a positive correlation between dry matter and phosphate soluble in distilled water. The value for r is .42.

r for dry matter and phosphate extracted by citric acid is only .24; for Morgan's solution there is no correlation.

The most satisfactory relationships between dry matter produced and nutrients are those between the former and the total nitrogen and the initial nitrate-nitrogen concentrations in the soil respectively. These are depicted in Figs. 7 and 8. The distribution of the points in Fig. 7 suggests that the straight line is a fair representation of the relation between total nitrogen and dry matter production. There the correlation coefficient is .84, which is eminently satisfactory. This value is unexpectedly high and is dealt with in some detail later on.

The correlation coefficient between the dry weights and initial nitrate-nitrogen concentration is practically as good, being .84.

The close proximity of these two values for r suggests that soil nitrogen and nitrate concentrations are closely correlated. Actually, the value for r is .77.

2. Nutrient Uptake

Potash

The relations between the potash taken up by the plant and the amounts extracted from the soil in the solutions used are depicted in figures 9 to 11.

The values for correlation coefficients between potash contents in the plant and potash extracted from the soil are as follows:—

Uptake and: (1) Potash soluble in N/2 acetic acid	...	...	.76
(2) " " distilled water	...	...	.63
(3) " " 1 per cent. citric acid	...	...	.59

As has already been reported we have long used 1 per cent. citric acid for the estimation of potash in tomato soils and this has been the basis of our advisory work for many years. It has, of course, always been evident that some other extractant might yield more satisfactory values, hence the attempt earlier in this work to relate potash extracted by N/2 acetic acid to that extracted by citric acid. The correlation results now given suggest that N/2 acetic acid is, in fact, the best reagent to use and it is a cause for some satisfaction that this confirms a decision already made on a purely analytical basis.

If instead of the total potash in the plant the percentage of potash in the dry tissue is compared with potash extracted from the soil the value of r is .79.

Mention may be made at this stage of the possible use of the extracting solutions recommended by Morgan and Truog respectively. Both these solutions have been used for phosphate extraction but not for potash. The reason is purely one of analytical convenience. For the purpose of the

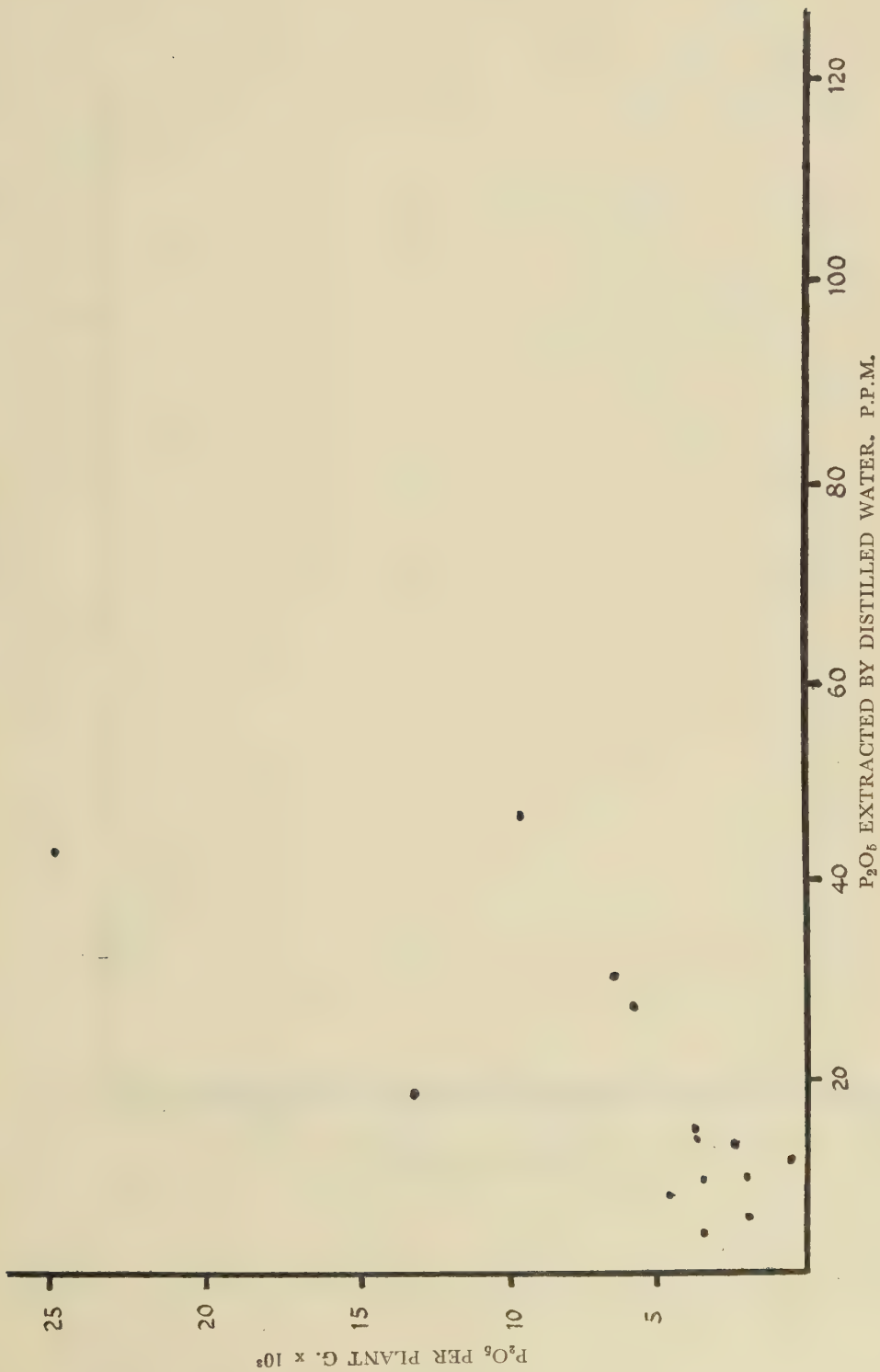


FIG. 13



FIG. 14

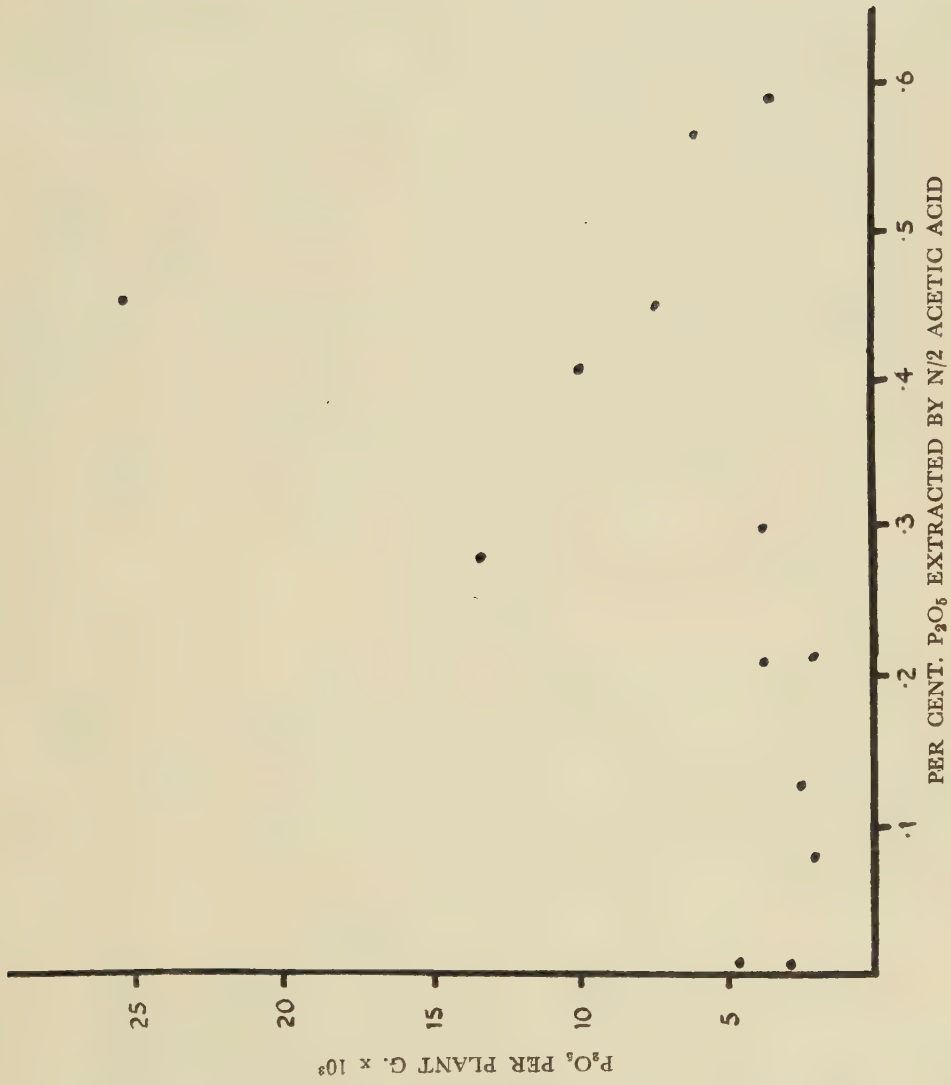


FIG. 15

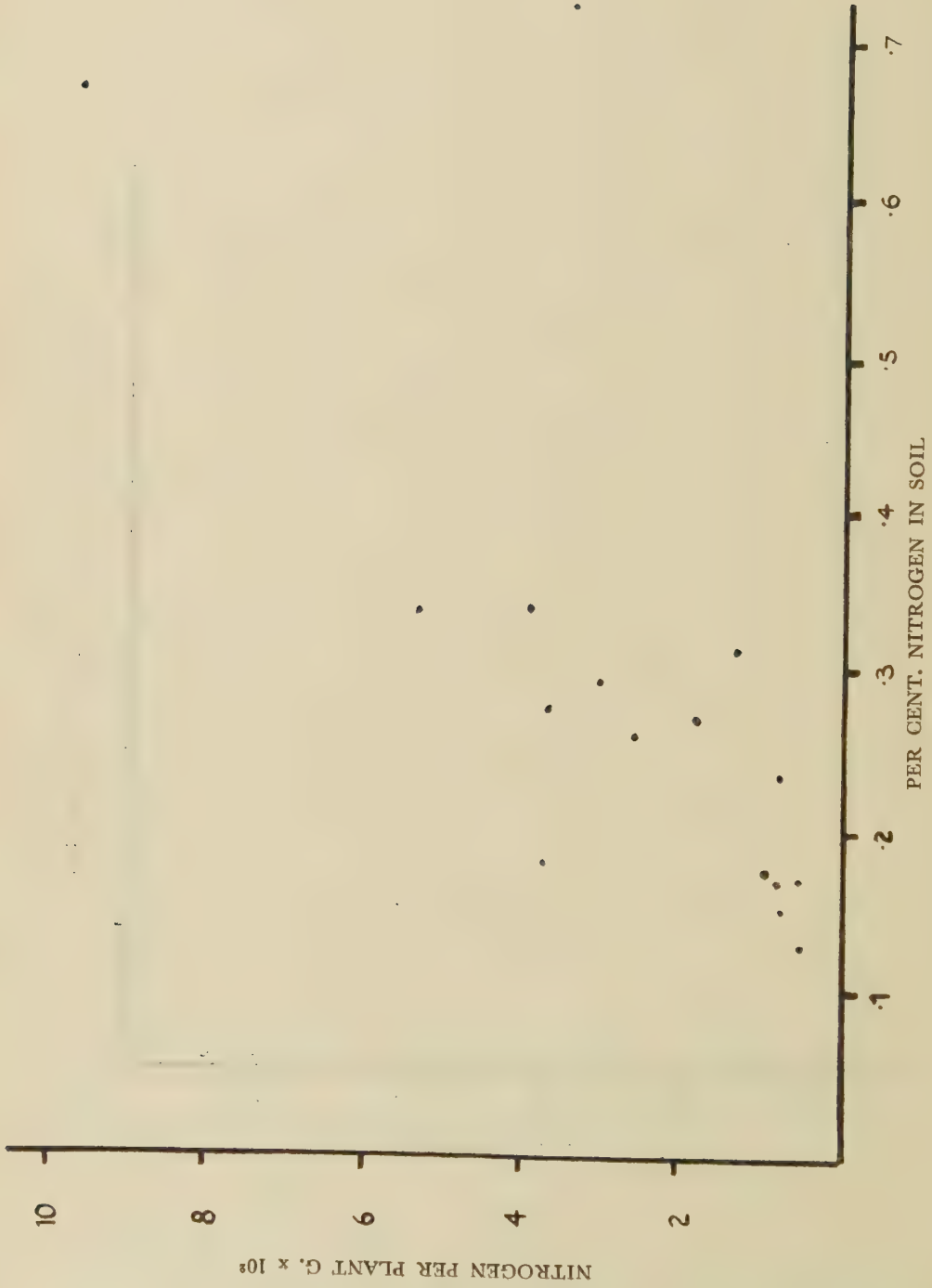


FIG. 16

present work it was decided that a fairly high standard of analytical accuracy was necessary. This meant that potassium had to be determined either by the perchlorate or by the platinum chloride method rather than by the cobalti-nitrite method. On the score of cost platinum was excluded, leaving the perchloric procedure. The sodium acetate in Morgan's solution made the first evaporation of extracts with added perchloric acid impossible without serious losses by spurting. In the case of Truog's solution removal of the sulphuric acid is an essential preliminary to the perchloric acid treatment and here the risk of losing potash in the barium sulphate separation was considered too high. These objections do not hold for the estimation of phosphate and these solutions were used for this determination.

Phosphoric Acid

Figs. 13 to 15 deal with phosphate extracted from the soils and that taken up by the plants. It was not expected that there would be high correlation here as extensive experience has shown that, providing that there is an adequate level of soluble phosphate in the propagating soil, tomatoes make satisfactory growth in the presence of comparatively little phosphate in the borders. In the present instance phosphate was adequate in the propagating mixture and there was more than sufficient phosphate for the plants in the experimental soils. Where phosphate uptake is low this is to be ascribed to limiting factors other than phosphate. In other words, phosphate uptake is limited as much by levels of other nutrients as by the level of phosphate itself. In this connection it has already been shown² that potash levels in the soil have a profound influence on the phosphate content of tomato foliage.

In the case of distilled water there is a correlation between the amounts of P_2O_5 and the amount taken up by the plant. At the lower values there is a linear relationship between the two, although the relationship breaks down at the high values. It appears that a concentration of 18-20 p.p.m. P_2O_5 would be the limiting concentration for normal growth and that no relationship would occur with values over 50 p.p.m. P_2O_5 in the soil. Examination of the percentage of P_2O_5 in the dry matter of the plant tissue shows that very seldom do we get a concentration of above 1 per cent. P_2O_5 in the dry matter of the plant tissue. It is thus likely that there is a limit to the concentration of P_2O_5 in the dry matter somewhere in the region of 1 per cent. P_2O_5 .

The actual values for the correlation coefficient are:—

(1)	Phosphoric acid extracted by distilled water	...	...	·63
(2)	" " " 1 per cent. citric acid	...	...	·51
(3)	" " " N/2 acetic acid	...	...	·43
(4)	" " " Morgan's solution	...	...	Not significant
(5)	" " " Truog's solution	...	...	" "

Nitrogen

Values for plant nitrogen and soil nitrogen are plotted in Fig. 16. The distribution suggests a positive correlation and the value calculated from the data for r is ·72 which is satisfactory.

The correlation between plant nitrogen and the initial nitrate concentration is better in that r is ·93. If they are compared with other values those for soil A (Tables I and II) are obviously abnormal and they probably make an unduly weighty contribution to the value of ·93. If the values of A are omitted from the calculation the value of r falls to ·78. If nitrogen uptake is plotted against the cube root of the nitrate concentration a better distribution of points results and a fairly straight line is obtained in Fig. 17. The line of best fit is the regression of plant nitrogen upon soil nitrate calculated from the equation—

$$Y = 0.0126 X - 0.0183$$

where X = (nitrate-nitrogen concentration)^{1/3}

and Y = predicted weight of nitrogen per plant.

The correlation here is highly significant in that $r = 0.94$.

The use of the cube root in this way is, of course, purely empirical. It does, however, suggest the view that utilisation of soil nitrate by the plant is limited by other soil factors.

Mention must be made of the results for soils A and C (Tables I and II). Both have unusually high nitrogen contents but show appreciable difference in the nitrogen uptake, that for A being much higher than that for C. The difference is explained partly by the fact that the initial nitrate-nitrogen in A is much higher than in C and partly by the fact that, as measured by all the methods used, the "available" potash and phosphoric acid are considerably higher in A than in C.

Discussion and Conclusions

Under the conditions of the experiments growth of young tomato plants is influenced mainly by the potash in the soil and the nitrogen status. The effect of soil phosphate is much less pronounced

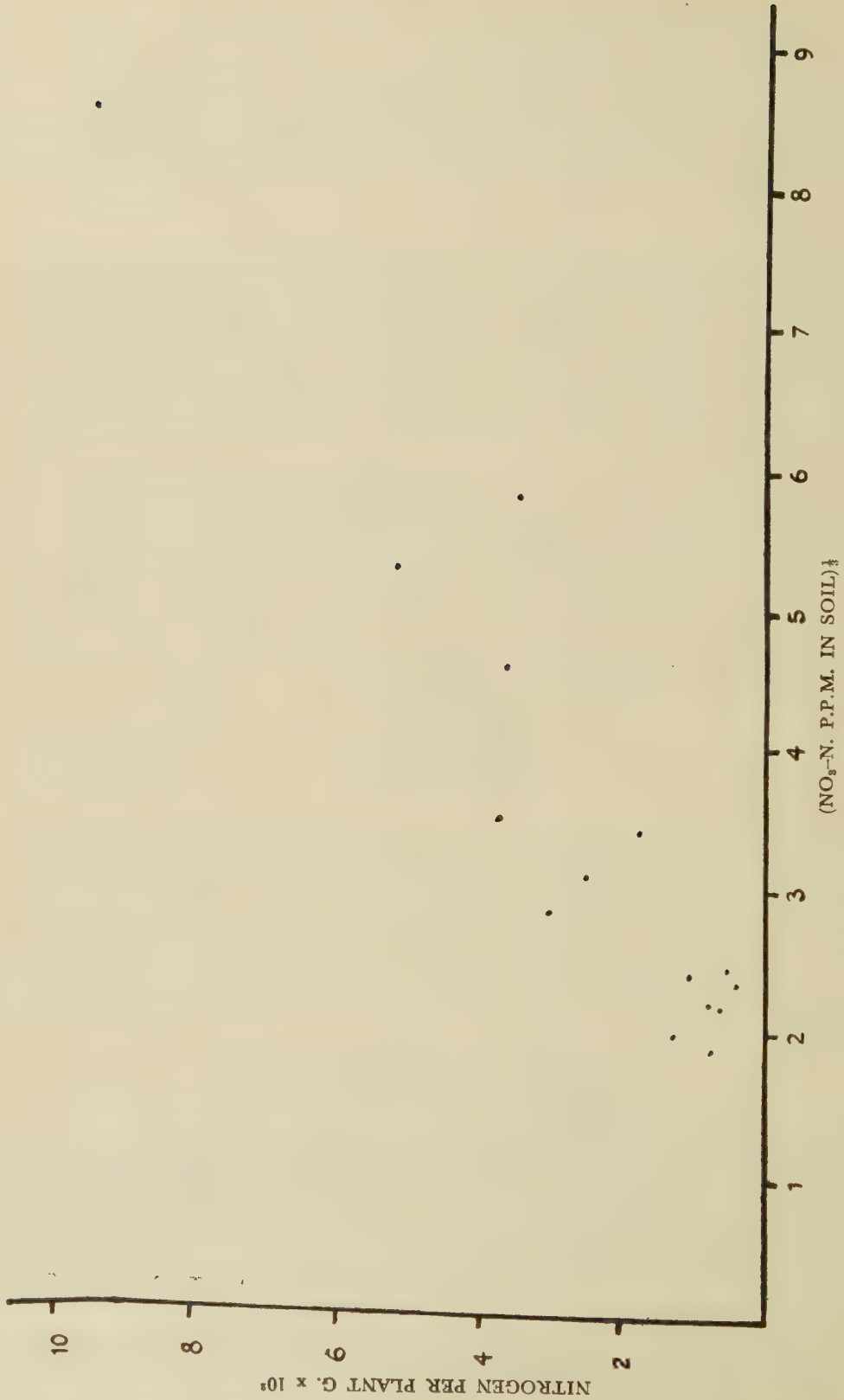


FIG. 17

and this is ascribed to the fact that the plants used were propagated in a standard commercial mixture which is rich in soluble phosphates. Our experience has been that beyond the propagating stage the demand for phosphate by the tomato plant is never high.

Of the extractants used for soil potash N/2 acetic acid is the most effective. Of those used for phosphoric acid distilled water is most satisfactory.

The high correlation between growth and soil nitrogen draws attention to the importance of the latter. It may be considered that the number of soils is too small to justify any conclusions regarding nitrogen or, for that matter, concerning potash and phosphates. Against this it may be stated that they were all soils likely to be encountered by the analyst and likely to be used in nursery work. Further, it did so happen that the total nitrogen values ranged from 0.13 to 0.72 per cent., which is quite comprehensive. That there was also a high correlation between growth and the initial nitrate-nitrogen concentration suggests a close connection between the latter and total nitrogen in these particular soils. Actually the value of r proved to be 0.77. This is quite in keeping with our experience of tomato soils. Usually it is considered necessary in soil analysis to determine the lime status and to make some assessment of available potash and phosphoric acid. Nitrogen, however, is frequently ignored on the grounds that "total" values do not necessarily yield any information regarding its availability. Presumably a nitrate determination is not carried out because of its transient nature.

At this Station soil analyses for advisory purposes have always included determinations of the total nitrogen by the Kjeldahl method. This has been used not only for making recommendations for nitrogen but also for organic matter and potash. It is therefore a cause for some satisfaction that the present work confirms the value of our previous practice. In our opinion the work also suggests that where soil analysis of tomato soil is considered necessary it should include total nitrogen which is relatively stable in the sense that it is not liable to fluctuations such as are to be expected in nitrate values.

Finally a word about the statistical treatment in this report. We have taken the view that the most useful relationship between nutrients in the plant and analytical data for the soil is a linear one. Consequently no attempt has been made to extend the treatment to curvilinear regression. Furthermore, the data are not considered sufficiently extensive to warrant examination, at this stage, of the interaction of the various soil factors by the methods of partial correlation.

Acknowledgement

We gladly acknowledge our indebtedness to our colleague, Mr. G. W. Winsor, for his valuable assistance in the statistical work involved.

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3. THE USE OF SODIUM ALGINATE IN COMPOSTS FOR PROPAGATING TOMATOES

by O. OWEN

Experience has shown that from the physical standpoint a suitable medium for propagating tomatoes consists of a mixture of stable manure and maiden loam. To this mixture are added lime and some fertiliser. The proportions of the ingredients used vary but a common mixture contains one part stable manure to five parts by bulk of loam. Such a mixture has been extensively used in the large-scale production of young plants. It would appear that the maiden loam may vary within fairly wide limits without any ill-effect but it is essential that the stable manure used should not be too fresh nor yet too old. In fact, the suitability of the latter is a matter of empirical experience and it is difficult to define a standard.

In recent years stable manure has been increasingly difficult to obtain, so various substitutes have been proposed and tried. A suitable substitute has been straw composted by the Adco or similar processes. Here again, however, it is not easy to advise a standard which will decide whether composted straw is or is not suitable. Another substitute which has been extensively used is peat. Before the War several brands of processed peat were available and some of these gave reasonably satisfactory results although it is doubtful whether they were as good as stable manure. During the War the branded peats were not available and it has not been easy to decide which of the many sources of peat offered to growers would provide satisfactory materials.

It was therefore a matter of considerable interest when Dr. Quastel¹ informed us of promising results he and Dr. Webley had obtained by using sodium alginate as substitute for some of the usual forms of organic material. Thanks to a generous sample of this compound provided by Dr. Quastel it has been possible to carry out a number of trials and this note gives an account of such trials.

Sodium alginate is a definite chemical entity and if it can, in fact, replace materials of uncertain composition and properties it will be possible to recommend a standard mixture for propagating tomatoes which should be applicable all over the country whenever young tomato plants are raised.

The results now reported suggest the material is very promising and that larger-scale trials are justified.

In the earliest experiments the compound was tried under two extreme sets of conditions. It was added at the rates of 1 and 2 per cent. respectively to two different soils. One was a very hungry, worn-out soil which had grown successive tomato crops for a number of years with very little addition of either artificials or organic material. The other soil was a rich one with high fertiliser and organic matter contents. Comparative controls were also used. The indications were that the alginate was without appreciable effect on the rate of germination of tomato seeds. These were, however, effects on the actual seedlings in the different sets. Where alginate had been added to the poor soil the seedlings were definitely better plants than in the corresponding control. Where alginate had been added to the rich soil, however, it had a definitely depressing effect.

There seemed to be a little difference between the two different concentrations of alginate used with either of the soils.

In the next experiments it was hoped to measure the effects of the alginate under more nearly commercial conditions of propagating. For this purpose a maiden loam was used and the effects of the alginate (again at concentrations of 1 and 2 per cent.) were compared with those of stable manure. Despite the usual precautions these experiments failed owing to a serious infestation of woodlice which appeared to show some preference for the seedboxes containing the alginate. A second batch of seeds suffered the same fate and what may be termed the normal season for sowing had passed. The indications from surviving seedlings bore out the preliminary observations, namely, that the alginate did improve the quality of the seedlings but had a depressing effect in the presence of stable manure.

Later in the year, experiments were again started and the indications were that seedlings in 1/100 alginate/soil mixture plus nitrogen, phosphate and potash were about as good as those in the standard soil/stable manure mixture but that where alginate was added to the soil/stable manure mixture there was a depressing effect.

Two rather more critical experiments were carried out with the following results.

Table I shows the results of the first experiment.

TABLE I

No.	Treatment	Maximum Height	Colour of Seedlings
1	Maiden soil alone	5 cm.	Dark green.
2	" " —superphosphate (1%)	5½ cm.	Medium.
3	" " —stable manure (17%)	10½ cm.	Dark green.
4	" " —" " " —1% superphosphate	10½ cm.	Good green.
5	" " —sodium alginate (1%)	2½ cm.	Dark blue.
6	" " " " " —superphosphate (1%)	6½ cm.	Good.
7	" " " " " —S.M. (17%)	9 cm.	Good.
8	" " " " " —superphosphate (1%)	9½ cm.	Good.
9	" " —sodium alginate (1%) —superphosphate (1%)—N-K ...	10 cm.	Good.

Seeds were sown in the ordinary commercial seed-boxes at the rate of 45 per box in accordance with our usual practice.

The variety Potentate was used. It usually happens that seedlings in the middle of these boxes grow taller than those at the edges and this accounts for the maximum height recorded in the table. The designation "good" and "good green" may be taken as being of a satisfactory commercial quality.

The nitrogen in treatment No. 9 was given in the form of hoof and horn and the potassium in the form of sulphate of potash, the amounts used corresponding approximately to the amounts of nitrogen and potash respectively in the stable manure used.

All the soil was sterilised by steam.

So that for our purposes Nos. 4 and 9 were comparable and the results showed how well the alginate compares with stable manure.

No. 7 again brings out the suggestion that the alginate has a depressing effect in what may be termed a rich soil.

In the final experiment, treatments were as shown in Table II—

TABLE II

No.	Treatment	Maximum Height cm.	Average Green Weight (g.)	Average Dry Weight (g.)	Remarks
1	2,500 g. maiden soil alone	7.5	.556	.052	Very dark colour, serious P deficiency.
2	2,500 g. " " plus 25 g. superphosphate ...	9.0	1.07	.086	Good colour.
3	*2,500 g. " " and stable manure	18.5	2.20	.148	Good colour.
4	*2,500 g. " " " " plus 25 g. superphosphate	18.5	2.43	.155	Good colour.
5	2,500 g. maiden soil plus 25 g. sodium alginate ...	4.0	.334	.036	Very dark colour, very serious P deficiency.
6	2,500 g. " " " " " " plus 25 g. superphosphate " " " " ...	9.5	1.15	.088	Rather darker than normal.
7	*2,500 g. maiden soil and stable manure mixture plus 25 g. sodium alginate	14.5	1.83	.130	Rather paler than normal.
8	As 7 plus 25 g. superphosphate	15.0	2.24	.167	Rather paler than normal.
9	2,500 g. maiden soil plus 25 g. sodium alginate plus 10 g. dried blood plus 10 g. sulphate of potash plus 25 g. superphosphate.	12.0	2.30	.150	Normal good colour.
10	2,500 g. maiden soil plus 25 g. superphosphate plus 10 g. dried blood plus 10 g. sulphate of potash.	9.0	1.40	.092	Rather dark colour, possibly excess N. effect.

* The maiden soil and the stable manure were mixed in bulk ratio of 5 : 1 and the whole sterilised with steam before use.

Again the variety Potentate was used and there was no appreciable effect on rate of germination. When all the seeds had germinated, however, differentiation of the effects due to the treatments soon became apparent.

Growth was what may be termed normal in Nos. 3 and 4, and the colour was satisfactory. These two were followed by Nos. 7 and 8 as regards height but the colour was not so good. Colour was quite satisfactory in No. 9 but growth not quite as good as in 7 and 8. The poorest growth was observed in No. 5 and the leaves were very dark in colour. Nos. 1 and 10 were little better than No. 5 as regards colour but they made more growth.

To make sampling possible in the poor boxes it was necessary to allow the seedlings to grow rather longer than is usual in commercial practice and this must be borne in mind when considering the tabulated results in Table II.

It should be added that for the average weight 12 plants were taken at random from each box. They were weighed as cut after removal of any foreign matter, and dried overnight at 105° C. Weights in Table II are the arithmetic means of the individual weights.

It is proposed to publish the detailed results elsewhere, but it may be stated here that the difference between the standard treatment (No. 4) and the corresponding alginate treatment (No. 9) is not statistically significant. Nor is the difference between treatments Nos. 3 and 4 significant. This latter indicates the maiden soil used in the experiment was richer in phosphate than is usually the case.

To test the possible use of sodium alginate at the potting stage, seedlings of the same height at the correct stage for potting were very carefully freed from soil and potted up in 3-in. pots in three lots. The mixtures used were:—

- (1) Maiden soil plus superphosphate (1 per cent.), dried blood ($\frac{1}{2}$ per cent.), and sulphate of potash ($\frac{1}{2}$ per cent.).
- (2) As (1) plus 1 per cent. sodium alginate.
- (3) Maiden soil (5) and stable manure (1) plus superphosphate (1 per cent.).

These plants (eight in each group) were allowed to grow under ordinary commercial conditions.

At the time they were ready for planting a commercial expert examined them and gave it as his opinion that there was little difference between Nos. 2 and 3. A second expert considered that No. 3 was very slightly better than No. 2. Neither knew of the respective treatments and the results may be regarded as satisfactory, and as indicating that there may be some use for alginate in this type of work.

The eight plants in each batch were cut off at soil surface, weighed and dried and weighed again. Average values were:—

				<i>Green Weight</i>	<i>Dry Weight</i>
No. 1	...	...	...	24.0 g.	2.404 g.
No. 2	...	...	...	22.1 g.	2.354 g.
No. 3	...	...	...	22.6 g.	2.485 g.

The differences are slight and have no statistical significance.

Further developments are in hand.

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APPENDIX "A"

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APPENDIX "B"

MANURIAL TREATMENT IN TOMATO EXPERIMENTS

(Except plots in Appendix C)

House	Plot	BASE TREATMENT						TOP DRESSING							
		Sterilisation	Lime	Stable Manure	Hoof and Horn	Bone Meal	Sulphate of Potash	Sulphate of Ammonia	Sulphate of Potash with first watering	Balanced Mixture	Dried Blood Mixture	Sulphate of Ammonia	Super-phosphate	Sulphate of Potash	Dried Blood
1	4	Steam	1 ton per acre	None	10 cwt. per acre	10 cwt. per acre	10 cwt. per acre	10 cwt. per acre	5 cwt. per acre	5 applications	1 application				
	6	"	"	"	"	"	"	"	"	"	"				
	10	"	"	"	"	"	"	"	"	"	"				
	15	"	"	"	"	"	"	"	"	"	"				
	1	Formaldehyde	"	"	"	"	"	"	"	"	"				
	9	"	"	"	"	"	"	"	"	"	"				
	11	"	"	"	"	"	"	"	"	"	"				
	13	"	"	"	"	"	"	"	"	"	"				
	2	Unsterilised	"	"	"	"	"	"	"	"	"				
	5	"	"	"	"	"	"	"	"	"	"				
	7	"	"	"	"	"	"	"	"	"	"				
	14	"	"	"	"	"	"	"	"	"	"				
	3	"	None	None	None	None	None	None	None	None	None				
	8	"	"	"	"	"	"	"	"	"	"				
	12	"	"	"	"	"	"	"	"	"	"				
	16	"	"	"	"	"	"	"	"	"	"				
3		Steamed	1 ton per acre	30 tons per acre before steaming	None	None	10 cwt. per acre		5 cwt. per acre	5 applications	1 application				
4	4	Steamed	1 ton per acre	None	None	None	10 cwt. per acre		5 cwt. per acre	5 applications	1 application				
	5	"	"	"	"	"	"		"	"	"				
	6	"	"	"	"	"	"		"	"	"				
5	1	Steamed	1 ton per acre	None	None	None	10 cwt. per acre		5 cwt. per acre	5 applications	1 application				
	2	"	"	"	"	"	"		"	"	"				
	7	"	"	"	"	"	"		"	"	"				
	8	"	"	"	"	"	"		"	"	"				
	3	"	None	"	"	"	"		"	"	"				
	4	"	"	"	"	"	"		"	"	"				
7	1	Formaldehyde	1 ton per acre	15 tons per acre	10 cwt. per acre	10 cwt. per acre	10 cwt. per acre		5 cwt. per acre	3 applications	4 applications				
	2	"	"	"	"	"	"		"	"	"				
	7	"	"	"	"	"	"		"	"	"				
	8	"	"	"	"	"	"		"	"	"				
	3	"	"	"	"	"	"		"	"	"				
	6	"	"	"	"	"	"		"	"	"				
8	1	Formaldehyde	1 ton per acre	15 tons per acre	None	10 cwt. per acre	10 cwt. per acre	10 cwt. per acre	5 cwt. per acre	None	None	5 cwt. per acre	10 cwt. per acre	10 cwt. per acre	
	2	"	"	"	"	"	"	"	"	"	"	"	"	"	
	3	"	"	"	"	"	"	"	"	"	"	"	"	"	
	4	"	"	"	"	"	"	"	"	"	"	"	"	"	
	5	"	"	"	"	"	"	"	"	"	"	"	"	"	
	6	"	"	"	"	"	"	"	"	"	"	"	"	"	
	7	"	"	"	"	"	"	"	"	"	"	"	"	"	
	8	"	"	"	"	"	"	"	"	"	"	"	"	"	
9	1	Formaldehyde	1 ton per acre	15 tons per acre	None	10 cwt. per acre	10 cwt. per acre	10 cwt. per acre	5 cwt. per acre	None	None	5 cwt. per acre	10 cwt. per acre	10 cwt. per acre	
	2	"	"	"	"	"	"	"	"	"	"	"	"	"	
	3	"	"	"	"	"	"	"	"	"	"	"	"	"	
	4	"	"	"	"	"	"	"	"	"	"	"	"	"	
	5	"	"	"	"	"	"	"	"	"	"	"	"	"	
	6	"	"	"	"	"	"	"	"	"	"	"	"	"	
	7	"	"	"	"	"	"	"	"	"	"	"	"	"	
	8	"	"	"	"	"	"	"	"	"	"	"	"	"	
10		Formaldehyde	1 ton per acre	15 tons per acre	10 cwt. per acre	10 cwt. per acre	10 cwt. per acre	None	5 cwt. per acre	5 applications	1 application				
	1	None	1 ton per acre	15 tons per acre	10 cwt. per acre	10 cwt. per acre	10 cwt. per acre		5 cwt. per acre	3 applications	2 applications				
	2	"	"	"	"	"	"		"	"	"				
	3	"	"	"	"	"	"		"	"	"				
12	1	None	1 ton per acre	15 tons per acre	10 cwt. per acre	None	10 cwt. per acre		5 cwt. per acre	None	None	None	+	None	+
	2	"	"	"	"	"	"		"	"	"	"	"	"	"
	3	"	"	"	"	"	"		"	"	"	"	"	"	"
	4	"	"	"	"	"	"		"	"	"	"	"	"	"
Rose House			Steamed	1 ton per acre	None	None	None	10 cwt. per acre	5 cwt. per acre	5 applications	1 application	None	None	None	None

APPENDIX "C"

MANURES APPLIED IN PLOTS 1-3 AND 8-10 IN TOMATO HOUSE 4

Plot	Title	Base Manure in Lbs. per sq. yds.				*Top Dressing in Lbs. per sq. yds.		
		Lime	Stable Manure	Super- phos- phate	Sulphate of Potash	Super- phos- phate	Sulphate of Ammonia	Sulphate of Potash
1	Complete Artificials (I) less Nitrogen	1.0	—	0.4	0.1	0.5	—	0.2
2	Unmanured	1.0	—	—	—	—	—	—
3	Complete Artificials	1.0	—	0.4	0.1	0.5	0.2	0.2
8	Complete Artificials with Dung	1.0	7	0.4	0.1	0.5	0.2	0.2
9	Complete Artificials less Phosphate	1.0	—	—	0.1	—	0.2	0.2
10	Complete Artificials less Potash	1.0	—	0.4	—	0.5	0.2	—

*The Top-dressing was applied in eight equal instalments.

APPENDIX "D"

DATES OF CULTURAL OPERATIONS, 1947

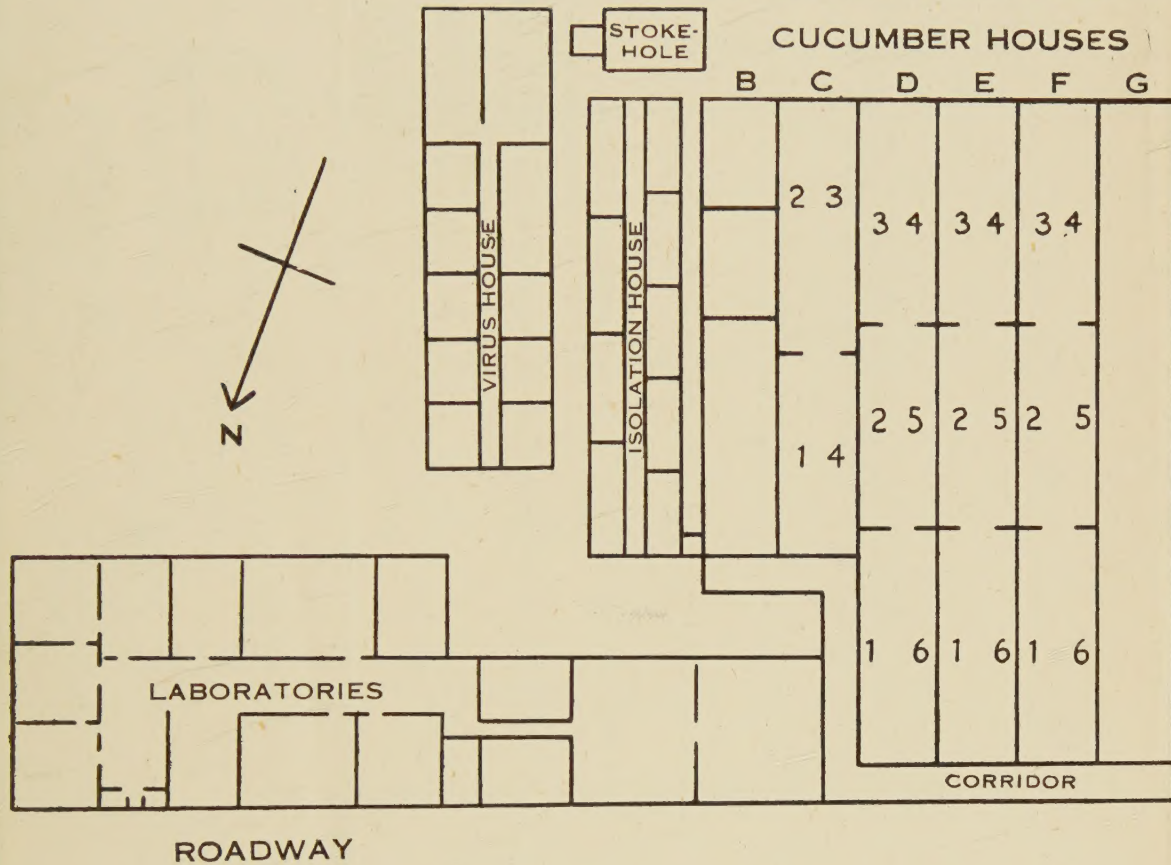
Crop	Sown	Potted into 60's	Potted into 32's	Planted out in Borders	First top Dressing	First Fruit Picked	Last Feed Applied	Last Fruit Picked
Tomatoes	Jan. 14	Feb. 10	—	Mar. 19	May 23	May 27	Aug 30	Oct. 10
Cucumbers	Mar. 7	—	May 17	Apr. 10	May 21	May 5	Aug. 14	Oct. 29

APPENDIX "E" METEOROLOGICAL RECORDS, 1947

Month	Air Temperatures				Grass Temperatures				Rainfall				Mean Soil Temperatures		Hygrometer				Bright Sunshine		Barometer	
	Mean		Absolute Maximum		Absolute Minimum		Av. Min.	Temp.	Date	Total Precipitation	No. of Days	Amt.	Date	1 ft.	2 ft.	D Bulb	Depos. of Wet Bulb	Relative Humidity %	Dew Point	Total No. of Hours		Daily Average
	Max.	Min.	Temp.	Date	Temp.	Date																
	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.		° F.
JANUARY	...	40.4	29.5	54.0	16th	9.0	28th	25.4	9.0	28th 29th	16	0.55	8th	36.1	39.1	34.4	0.5	94.5	32.9	58.1	1.9	29.96
FEBRUARY	...	33.1	25.9	42.0	26th	7.0	23rd	23.5	2.0	24th	10	0.35	3rd	32.7	35.3	29.6	0.8	86.0	25.9	27.1	1.0	29.71
MARCH	...	46.3	34.0	58.0	30th	17.0	6th	29.1	8.0	6th	23	0.84	29th	36.4	37.1	40.0	0.4	96.0	38.9	58.9	1.9	29.54
APRIL	...	59.0	40.5	71.0	16th	28.0	9th	31.4	19.0	9th	11	0.37	2nd	47.2	46.2	48.3	2.4	83.9	43.3	154.1	5.1	30.01
MAY	...	68.5	47.3	88.0	30th	38.0	4th	—	—	—	12	0.21	2nd	54.7	53.2	57.5	3.1	82.1	51.8	190.9	6.2	29.97
JUNE	...	73.6	52.5	94.0	3rd	40.0	12th	—	—	—	12	1.13	27th	62.7	59.8	63.2	3.6	80.4	56.7	206.0	6.9	29.94
JULY	...	76.7	56.5	91.0	31st	46.0	21st	—	—	—	9	0.83	19th	65.9	63.1	65.5	2.8	84.7	60.5	164.0	5.3	29.93
AUGUST	...	80.3	54.8	91.0	1st 2nd	44.0	7th	—	—	—	3	0.04	2nd	65.1	63.5	66.7	3.8	79.1	59.8	276.9	8.9	30.10
SEPTEMBER	...	71.8	49.8	84.0	11th	34.0	30th	—	—	—	8	0.84	17th	58.6	60.2	61.3	1.8	88.9	57.9	137.2	4.6	30.02
OCTOBER	...	61.2	40.8	73.0	6th	29.0	20th 29th	—	—	—	4	0.09	22nd	49.8	53.0	49.1	1.2	91.9	46.7	90.1	2.9	30.10
NOVEMBER	...	51.2	37.9	63.0	9th 23rd	20.0	30th	—	—	—	10	0.21	9th	45.1	48.0	45.4	0.7	94.8	43.9	60.5	2.0	29.89
DECEMBER	...	46.6	36.4	54.0	26th 27th	22.0	30th	—	—	—	17	0.55	25th	41.7	44.2	41.9	0.6	95.0	40.6	21.1	0.7	29.93

Total Rain for Year: 20.39 inches. Number of Days Precipitation: 135. Total Bright Sunshine for Year: 1,444.9 hours.

DIAGRAM SHEWING ARRANGEMENT



No. 1

8	9
7	10
6	11
5	12
4	13
3	14
2	15
1	16

OF EXPERIMENTAL PLOTS, 1947

TOMATO HOUSES

